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SCHOOL OF MEDICINE.

AN INTRODUCTION TO BIOLOGY.

BY

ARTHUR LOOSS, PH.D.

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SCHOOL OF MEDICINE.

AN INTRODUCTION TO BIOLOGY.

A SERIES OF LECTURES DELIVERED TO THE STUDENTS OF THE FIRST YEAR

BY

ARTHUR LOOSS, PH.D.,

Professor of Biology and Parasitology,
School of Medicine, Cairo.

Honorary Member of the Association of Economic Biologists, London.—Member de
l'Institut Egyptien.—Foreign Member of Göteborg's Kongl. Vetenskaps och Vitterhets
Samhälle.—Membre Associé de la Société de Pathologie Exotique,
Paris.—Membre Correspondant de la Société Royale des Médecins,
Budapest.—Corresponding Member of the Zoological
Society, London.—Corresponding Member of the
Helminthological Society, Washington.

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PREFACE.

The present book presents in print the essential contents of about ninety lectures on Biology delivered to the First Year students of the Government School of Medicine, Cairo.

The limited amount of time available necessitated a commensurate restriction of the subject. The items actually chosen for discussion were selected with the view of combining, so far as this was possible in a course of general Biology, the explanation of biological phenomena with the description of organisms that more particularly interest the Medical Man and the Hygienist. Throughout the book, special stress has been laid on the fundamental facts and their mutual connections as we at present conceive them, while details and variations have been omitted, or merely alluded to.

The diction adopted may appear to many very elementary, but seemed to be the best means for the attainment of the author's first and foremost purpose, namely, to be understood even by the quite uninitiated.

The illustrations appended are in part original drawings, in part copies, or combinations, of figures published in text-books or special treatises by previous authors. All of them are more or less diagrammatic, in agreement with the general tendency of the text.

To some of his colleagues the writer is indebted for information and literature about questions with which he was himself less familiar, and to those gentlemen he tenders his best thanks. In particular he desires to express his gratitude to Dr. Keatinge, Director of the School of Medicine, both for much good advice and the wearisome work of revising the text of the whole book, and to Mr. Mangan, his Assistant, for collaboration in reading the proofs.

AN INTRODUCTION TO BIOLOGY.

Gentlemen,—

I am here to give you a course of lectures on "Biology". Before going into the subject, I must emphasise a point of general importance. We have to discuss our subject from a scientific point of view, and in doing so we have to use scientific language. Science in the course of its development has become acquainted with an ever-increasing multitude of conceptions which in part refer to newly discovered creatures, in part to processes in their life, or stages in their development, not hitherto recognised. Most of these conceptions are of such a nature that it would be impossible to shortly and clearly express them in everyday language; and yet it is absolutely necessary for the advancement of exact science that there should be precise and unmistakable designations for all these ideas. Thus scientists have invented, and are still constantly inventing, new words for the new conceptions, and in order to make these quite precise as to their meaning, take them from languages at present no longer spoken, viz. from ancient Greek and Latin. The new designations are for the most part combinations of two or more independent words, which as far as possible directly describe the creature, or process, to be indicated by the name. Thus, for anybody who is familiar with the old languages, the meaning of any scientific "technical term" is usually easy to find by a simple translation of the original words;

and since their meaning is known, the entire names are also easily retained in memory. You are unfortunately not acquainted with the dead languages, and thus I know from experience that, especially in the beginning, you find difficulty, both in understanding these technical terms and in remembering them afterwards. However, I must warn you at the very beginning that you will have to learn them, for they form an integral part of our scientific language and in one word indicate, precisely and definitely, what otherwise would have to be explained by a long description. In order to help you in the task of making yourselves acquainted with our technical terms, I will give, for all those which we have to use here, the English translation of the component Greek or Latin words; you will find, by degrees, that many of them occur again in other combinations and, knowing their meaning, you will experience an ever diminishing difficulty in retaining them in your memory.

At the threshold of our subject, we find ourselves face to face with a technical term: "Biology". The word is derived from ancient Greek, the first part, βίος meaning "life" (βίον the "living being", βιόω to live), the second part, "λόγος", having a somewhat wide sense, which in our case (and some other instances) may be translated by "science". Biology, therefore, is the science which studies the "living beings", or "life" in general. This definition naturally leads to the question: What is a "living being"? or: What is "life"? Your everyday-experience enables you to tell that a horse dragging a carriage, or a tree growing in a garden, in fact all those things which we call "animals" and "plants", are living beings; nor are you in doubt that a beetle preserved in some museum, and a dry clover-plant from the fodder of a cow, though no longer "alive", yet once have been "alive"; whereas a piece of rock, or a crystal of some mineral, or a drop of water, are not "alive" and have never been "alive". All this is perfectly correct, but in science we have, if possible, to find out precisely the differences which separate the "living beings" from all the other things to which we do not give that name. With this discussion we enter into our subject proper.

CHAPTER I.

On the Distinctive Characters of Organisms : The Manifestations of Life.

To begin with, I will mention that we combine all "living beings" under the common denomination of "**Organisms**"; the reasons for our doing so will be given later (p. 30). Animals and plants, therefore, are organisms; rocks, minerals, water, air, and so on, are "**Anorganisms**" *. The dead beetle and dried clover-plant mentioned above remain organisms, although they have ceased to "live"; even a piece of cloth, or a sheet of paper, or the ivory-handle of a knife, remain "organic" as to their nature, because they owe their origin to, or are artificially made of material produced by, some previously existing organism. The **distinctive differences** between organisms and anorganisms, from the scientific point of view, are found in the fact that, in the former, "life" manifests itself, or at least has manifested itself, by a number of phenomena †, so-called "**Vital Functions**", which are totally absent in the latter. Let us now see what these functions are.

Starting from ourselves, you know that we cannot live without **Feeding.** Indeed, every organism must take up food, in contradistinction to the anorganism, which does not need any. The nature of this food varies considerably with the various organisms, as we shall see in detail later; for the present, it may suffice to state that it is partly solid and partly fluid. In the former case, in everyday-language, we speak of "food"; in the latter, we speak of "drink"; but from the biological point of view, liquids also, even water, must be considered as a particular form of "food". Within the body the food, of whatever description it may have been before, never remains as it was, but is changed in such a way that substances result which can be utilised by the organism for its particular purposes; what these purposes are we shall see in due time. I will at once mention in this connection that the transformation of the original food going on in the organism, and a number of other transformatory processes intimately associated with it, are scientifically combined under the term "**Metabolism**" *. Thus feeding plays a part in the general metabolism and is a first "manifestation of life".

---

* The Greek syllable ἀ or ἀν — grammatically called "alpha privativum" — means that something is not what the second word indicates; anorganisms therefore is to be translated "non-organisms".

† Φαινόμενος (from φαίνω—to show, to make appear) means "all that is visible, observable", and is very frequently used in scientific language in this sense.

A second is equally well known to you. If by some accident a man gets into surroundings to which air has no access, he will become "suffocated"; the air, or, more precisely speaking, the oxygen of the air, is indispensable to him for maintaining life. The process of taking in the air is called "**Respiration**"; if we enquire into its nature a chemical analysis shows that it is a process of **oxydation**; in other words, that the oxygen of the air taken into the body is used there for **burning** certain substances. For the "exhaled" air proves to be poorer in oxygen than was the "inhaled" air, and to contain, instead, an increased amount of carbonic acid and water-vapour. This inhalation of oxygen and exhalation of carbonic acid and water is peculiar to all organisms, but entirely absent in anorganisms.

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* Greek, μεταβολή—change, transformation; the word in this case particularly refers to the change of substance going on within the organism in connection with feeding.

All organisms must respire; in some, as in Man and the higher animals, the process is easily observable; an example showing that it may also be very apparent in lower animals, will be mentioned later (p. 451). In others, it is less evident, but nevertheless present. You know that fish live in water, in which a man would be "drowned", i.e. suffocated from the absence of air. This apparent contradiction is explained by the fact that the fish is capable of immediately absorbing that oxygen which under natural conditions is always dissolved in water, whereas Man, and all "air-breathing" animals, are unable to do the same. Take a glass of water from the tap and allow it to stand for a couple of hours, or slightly warm it: you will observe that soon very fine bubbles appear along the wall of the glass; they are chiefly composed of oxygen which was absorbed in the water, and is now gradually being given off. It is this oxygen which the fish respire. If you keep one in a receptacle you will see that it is constantly taking in, seemingly "swallowing", water by its mouth; there you see the external signs of respiration, for the fish does not actually swallow the water. If you lift the bony plates situated on either side of its head you will see beneath them several fringe-like structures of a livid red colour, the "gills", or respiratory organs of the fish. Between these, there are large gaping openings which communicate with the mouth, and the water, though apparently swallowed, after having bathed the gills, escapes by them, slightly lifting the bony lids which cover the gills with each expulsion.

If the receptacle in which you keep fish is comparatively small the amount of oxygen dissolved in the water will soon be used up. When this happens you may observe that the fish come to the surface of the water and "swallow", in addition to water, small bubbles of air. In this way they try to make up for the deficiency of oxygen in their natural surroundings; but it is only necessary to prevent them, by some means or other, from coming to the surface and they will die from suffocation as all animals do if deprived of air.

In still other organisms, the process of respiration is not externally indicated by any visible sign, but is going on notwithstanding. The egg of a hen, for instance, is "alive", for (if it is fertilised) a young chicken develops in it. This must respire, and it does so by the help of minute pores, or holes, which traverse the hard egg-shell and thus enable the oxygen to reach the inside of the egg. But try to exclude the air from such a developing egg by covering it with some varnish or oil (which closes the pores), and the chicken will invariably die from suffocation. Plants also respire as animals do. The process is not outwardly recognisable, but can be demonstrated by experiment; this point will be returned to in Chapter IX (p. 269). Thus respiration is common to all organisms; but as it is not shown by any anorganism, it is a "distinctive character" of the organisms.

In Biology we often compare the living organism with an **engine**, and a very instructive comparison this is. Every engine is devised for some purpose, in other words, is constructed for doing some particular work. It does not work, however, unless it is given the necessary power. This may be produced in various ways, but is usually (think, for instance, of a locomotive) the expanding power of water-vapour. Water-vapour is produced by heat, and the heat, in its turn, is produced by burning fuel; ultimately, therefore, this latter process is the source from which the engine receives the power for working. You will learn in Chemistry that every combustion, whether accompanied by externally visible signs (such as flames) or not, is the process of the burning substance combining with oxygen, and is, further, invariably connected with a rise of temperature. In order therefore to keep an engine working, a constant supply of fuel and oxygen are necessary; as soon as the one or the other are wanting, the engine cannot work.

Now if we look at the living organism, and remember that by its respiration it constantly burns certain substances, it becomes probable that this process is also meant to supply the power for doing work. And work the organism does. The performance of the vital functions (which include not only feeding and respiring, but the others we shall have to speak of later) is a labour which, as any other labour, requires an equivalent energy for its execution. The animal organism even shows with special clearness that it can produce power like an engine; indeed, before the invention of the engine this source of power was, with the exception of wind and water, the only one of which Man was cognisant, and even to-day the power produced by human beings and certain animals such as horse and cattle is almost exclusively used in agricultural work in Egypt. However, as the engine requires fuel as a second indispensable prerequisite for working, so the organism requires food for the same purpose. It is a well-known thing that a starving man cannot do hard labour, and in many different languages there are fairly identical sayings to the effect that a man, or an animal, when they are required to work, should also be given to eat. Thus the food is to the animal what the fuel is to the engine, namely, a **source of energy**.

We have stated above that every process of combustion produces heat. Therefore, if a similar process is going on in the organism in association with its respiration, we ought to expect that, in this, it equally causes a **rise of temperature**. The inference is borne out by facts; the only difference is that the respective temperature is easily perceptible in certain organisms, but is only slightly apparent in others. You have certainly noticed that Man, or a horse, or a bird, when you touch them, "feel warm", whereas a fish, or a frog, "feel cold"; we practically speak of "**warm-blooded**" and "**cold-blooded**" animals, and thereby indicate that, in the one case, the organisms have a temperature of their own noticeably above that of their surroundings, whereas, in the other, they have apparently not. I say "apparently", because careful measurements have shown that even "cold-blooded" animals have a temperature of their own, but so little raised above that of the environment that it is not noticeable by simple touch (for a special example see p. 191).

In order to understand this difference between warm-blooded and cold-blooded animals, let us remember an instance occurring in daily life. We may light a fire at some place exposed to the air, and it will burn and give a certain temperature. But we may greatly intensify the process of combustion, and increase the temperature of the fire, by artificially increasing the access of air with bellows or similar contrivances. Looking at the respiration of the organisms from this point of view, we perceive that it goes on with much greater energy in the warm-blooded animals than it does in the others. Reserving details for a later discussion (see p. 453), I will only recall here that we, for instance (and all warm-blooded animals in general), take in the air with a certain force and in such an amount that the chest becomes visibly dilated; but even this amount suffices only for a short time, for we must replace it by another supply after a few seconds. No signs of an equally intense respiration are observable in a fish or a frog. Indeed, their respiration goes on with much less energy, and hence the only slight rise of their temperature above that of the surrounding medium.

However, a certain temperature is not only produced by every organism, it is even necessary for it to perform the functions of life. We have just seen that the warm-blooded animals produce a comparatively high temperature; they are therefore to a large extent independent of that of their surroundings; in other words, they are capable of performing the vital functions equally well in warm weather and in cold weather. This is different with the cold-blooded animals and, generally speaking, with all the organisms that produce only a slight temperature. If they are placed in a cold environment their own little warmth is soon swallowed up, as it were, by the surrounding cold, and their temperature sinks to that of the latter. From the fact just mentioned, that a certain temperature is necessary for every organism to fully perform the functions of life, it would logically follow that, if that temperature is not present, the organism can no longer fully perform those functions. This is indeed the case, and it leads to a number of consequences, some of which are certainly known to you from daily experience.

During the cold season, in this country, many animals seek sunny places "to warm themselves". They, biologically speaking, do nothing else but try to get from the rays of the sun compensation for the loss of temperature caused to them by the coolness of the surrounding air. Further, many animals behave very differently according to whether the weather is warm or cool. To mention one example only, let me refer to that kind of lizard called in Arabic هردون (*Stellio vulgaris*). It is especially common along the seashore, and during the warmth of the day is so sharp-sighted and so quick that it is almost impossible for a man to catch it. But it is easy to collect it if we seek for it just before sunrise on a cool winter-morning. The creatures then rest on the branches of trees, and it is simply necessary to give the branch a knock with a stick to make them fall to the ground, where they remain motionless and can easily be picked up. It is exclusively the low temperature which so remarkably changes their behaviour, for if we put them into a cage and expose them to the sun, they will speedily recover their alertness, only to lose it again with a new fall of the thermometer.

You further know that plants grow much more intensely in the warm season than they do in the cool. In this country, even during the latter, the temperature hardly ever goes down to the freezing point, and, if so, only for a few hours. In northern climates, during the winter, the temperature may go much lower, and remain so, without great changes, for several months. These conditions exercise a very important influence upon the organisms inhabiting such countries. The cold, unless it is very intense, does not actually kill them, but reduces to a minimum, or totally inhibits, the performance of the functions of life. Many animals withdraw from the surface of the earth and bury themselves in the ground, where they remain in a kind of sleep; all the plants which do not normally die with the end of the summer entirely cease to grow, while many lose their leaves. Thus in the cooler climates the whole organic world, during the winter, goes through a period of quiescence, or, as we also express it, through a period of "**Latent Life**"*, only to awake again and to resume its normal activity with the return of spring. We thus see that, quite generally speaking, temperature plays a very important part in the life of the organisms. These all produce a certain warmth in connection with their respiration; but only in comparatively few is the respiration so intense and the temperature produced so high that it makes the respective organisms to a certain extent independent from the temperature of their environment; in the greater majority of organisms, the rise of temperature produced by less intense respiration is so insignificant that, with regard to the manifestations of life, they greatly depend upon the temperature of their surrounding, showing their vital energies fully only when it is warm, but falling into "latent life" when it becomes cold.

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* Latin, from "latere"—to be hidden, invisible.

I will mention here, by the way, that the reverse may happen in very hot and dry countries, in so far as in these many animals (especially those lower on the scale) and plants go through a period of latent life during the hot season; the reason being, in these cases, not so much the temperature, as the absence of water, which under ordinary circumstances makes life impossible.

We must now return to the instance of the steam-engine. We saw that, in order to make it work, it must be supplied with fuel and air. By the combustion of the fuel, various chemical combinations, but chiefly carbon-dioxide and water, are formed. Even with the best supply of air, however, not all the fuel can be burned; it usually contains substances which are not "combustible" and remain behind in the form of ashes. Both these and the actual products of combustion must be carefully removed from the engine in order to keep it fit for work; it is by no accident that in every steam-engine we find a chimney and a grate; they are added because they are necessary. If we now look at the organism we again see a very interesting parallel. For just as respiration is likewise a process of combustion, so its products, namely, carbon-dioxide and water, are also quite regularly evacuated from the organism by the fact of exhalation. As to the "fuel", the food is of very different nature in the different organisms; there is, in this respect, quite a particular difference between animals and plants. We shall return to this in detail on a later occasion (see pp. 259ff and 268); speaking at present of the food of animals, you know that it regularly contains a certain amount of "indigestible" substances which constitute the "**Fæces**" and must be removed from the organism just as the ashes from the engine. In addition to the fæces which in the main have a solid form, and to the products of combustion which are gaseous, the animal organism still produces certain substances in a liquid form. They chiefly contain nitrogenous matter and are generally called "**Urine**". The formation of carbon-dioxide, water, urine, and fæces is thus, in the living organism, intimately associated with the processes of feeding and respiring; the substances themselves are, or contain, "products of the metabolism", but as they are of no use to the organism, we call them "**Waste-Products**". As waste-products, carbon-dioxide, water, urine, and fæces must be eliminated; for it is not difficult to understand that, in the opposite case, their gradual accumulation in the body would sooner or later interfere with the normal function of the whole organism. This process of removal is called "**Excretion**", and it represents a third distinctive character between organisms and anorganisms.

I must add here that the term "excretion" is in practice specially used for the formation and removal of the liquid substances, although from the biological point of view it is closely connected with the two others and represents one part of the general process, the aim of which is the ridding of the organism of all those products of metabolism which are no longer of use. To conform to the general usage, however, and in order to avoid misunderstandings, we shall henceforward use the term "excretion" exclusively for the evacuation of liquid products. It should be pointed out, further, that the fæces, consisting chiefly of those parts of the food which could not be changed at all by the organism and hence corresponding to the ashes in the engine, are not exactly "products" of metabolism, but only contain such products.

Up to the present, the parallel between the organism and the engine was fairly complete; there is, however, a point in which they differ. In the engine, fuel, by its combustion, can only produce power; we may increase the supply of fuel as much as we like, it will not alter the engine, except, perhaps, that it may destroy it. For the organism, on the contrary, the food has a double significance; it is a source of energy, but also enables it to grow, that is, to transform a certain percentage of the food into organic substance and to add this to the already existing bulk of the body. The phenomenon is I think so familiar to you from both animals and plants that I need not quote examples. This **Growth** is another distinctive character of the organisms.

It is true that under certain conditions a crystal of some salt or mineral may also grow; but this increase in size is essentially different from that we observe in organisms. It can only take place if the substance of which the crystal consists happens to be present, in a dissolved condition, in its surroundings; and when it takes place, is merely due to a deposition of this substance, in a solid condition, on the surface of the original crystal. It never manifests itself in the active formation of fresh substance or the production of parts of the body not hitherto present, as it does in the animals and plants.

I may mention here that the former method of growth is scientifically termed growth by "**Apposition**"; it occurs here and there among the organisms, and special examples will be mentioned on pages 328 and 334. The latter method of growth peculiar to the organisms is called growth by "**Intussusception**"* because it is effected by the new particles of organic material being intercalated between those already in existence. Indeed, all organisms grow "from inside outward", as we may easily verify in a growing animal or the unfolding leaf of a tree, neither of which has anything deposited on its outside while it increases in size; its growth comes from within.

This may be a suitable place for pointing out some further interesting features about the growth of the organisms. If we look at the **plants** it is easy to see that they mainly **grow so long as they live.** We find apparently similar conditions at times in lower animals; there are, at any rate, indisputable observations on record that animals have been met with in sizes far beyond those which they are known to attain ordinarily. An example of which you have perhaps heard is supplied by a fish (*Lates niloticus,* Arabic إشر) which in the Nile reaches an average size of forty centimetres, but in the Karûn Lake (Fayûm) has been found in specimens measuring as much as 1·25 metres. **In Man and the higher animals,** on the other hand, **growth is limited** in so far as it goes on for a certain time and then comes to a stop. What interests us here is that after full size is attained the food loses its double significance and is utilised preponderantly, if not exclusively, for the production of energy. This may explain the well-known fact amongst others that Man does not as a rule display his full mental and physical powers until his growth is finished. It further explains that a man who works hard not only requires a full measure of food, but is also able to convert the whole into energy, whereas in a person who feeds well but does little or no mental or physical work the equilibrium between consumption and utilisation of food is disturbed. Hence the observation that well-to-do people (as also animals, e.g. pet-dogs, under similar conditions), even after the cessation of their normal growth, are prone to increase in circumference, the surplus of the food consumed, but not utilised, being stored in the body in the shape of fat. The biologically natural method of curing obesity would therefore be (apart from exceptions which do not interest us) an adequate reduction of nutriment; unfortunately, this prescription is neither easy nor pleasant to carry out practically.

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* From the Latin "intus"—into, and "suscipere"—to take up.

A fifth manifestation distinctive of organisms is **Movement.** It is especially conspicuous in **animals**; the more so, as these creatures are able to move at will. The phenomenon is so familiar to you that I need not say anything further in explanation. However, these "**voluntary movements**" are not the only ones that animals are capable of. Remember, for instance, the heart; the heart beats, but you cannot stop this beating at will. The movement of the heart is independent of will: it is an "**involuntary movement**". The same may be said of the movement of the intestine, to which we shall return at a later occasion. There is finally a third kind of movement which, although involuntary like that of the heart, is yet not made so constantly, but only on certain occasions. If, standing before you, I make, with my hand, a quick movement towards your face, you will blink your eyelids. Many persons, and also animals, give a jerk if a shot is fired in their neighbourhood; even the blushing and blanching of the face under certain conditions may be considered here, as they have their origin in certain movements of the blood-vessels. All these movements are involuntary, for in many cases we have made them before becoming aware of the fact. The distinctive thing about them is that they are immediately instigated by something happening outside. In the examples given above, you see the movement of my hand, and your movement is the "re-action" upon my action. In the case of the shot, it is heard, and the jerk is again a "re-action" to something that happened outside. As to the blushing or paling of the face, it is usually the result of a mental shock of some sort, and thus a "re-action" to this shock. All these movements are therefore neither voluntary nor regular, but are, as we put it in scientific language, "Reactions", or "**Reactive Movements**" to outward "**Stimuli**" *.

At variance from the animals, the **plants** at first sight seem destitute of mobility. However, this is not actually the case. It is true that, fixed in the ground as most of them are, they cannot move at will, neither from the spot, nor on the spot. But there are quite a number of very humble and simply organised plants which are not fixed and, in certain periods of their life, are capable of **active movement**, from the spot and on the spot, just as animals are. We shall speak of some such plants in detail later (e.g. p. 252f). Even the higher plants, such as you are wont to see about you, are not entirely incapable of movement; but these movements are only of the last type mentioned above, i.e. **reactive**

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* "Stimulus", Latin (from "stimulare")—anything that rouses or incites to action.

movements. Out of the many instances known I will give you a few. The standard example of a mobile plant is *Mimosa pudica*, common in many warm and damp countries, and often kept in hot-houses in cooler climates; in Arabic it is called الست المستحية. If this plant is in perfect rest, its doubly feathered leaves are spread out and stand off from the stem at about right angles. But you only require to suddenly touch one of the leaves, or, the plant being on a table, to give a sharp knock to the table, and you will see the small leaflets closing, and the petioles sinking down into a drooping position. The plant, by this movement, "reacts" upon the shock received. You all know the Lebbakh-tree (*Acacia lebbakh*, لبخ) which used to shade the streets of Cairo, and a similar tree of the country called سنط (*Acacia nilotica*); if you look at their leaves during the day you will find that they are fully spread out; but if you look at them again towards or after sunset you will see that they are closed and drooping, to open again with the light of the next morning. These movements of opening and closing are quite regular, and there is no doubt that they are caused by the variations in the intensity of the light. They are therefore "reactions" on the part of the plant to the variations of light.

There are still other stimuli of both chemical and mechanical nature which induce certain plants to make reactive movements; I must refrain here from giving details and limit myself to the statement that they exist. The instances described will suffice to show you that plants also are capable of moving, though most of these movements are only reactive in nature.

If a plant is able to make such a reactive movement, that is to answer as it were to some stimulus coming from outside, there is the logical necessity that it must previously in some way feel or notice that stimulus;

in scientific language: the plant must be "irritable". **Irritability** is indeed a sixth distinctive character of the organisms. It is very probably developed in all organisms, although, in plants, we cannot demonstrate its existence except in the comparatively few cases where these react to outward changes by signs apparent to our methods of observation. It is very probable that many plants, perhaps all plants, notice the variations in the intensity of the light as the Lebbakh-tree does, but since they do not answer to these variations by externally visible movements, we are not sure of the fact.

Movements of various sorts are indeed the usual signs by which organisms show that they are irritable. This is easily observable in animals: I think it will suffice here to recall in proof the reactive movements of Man enumerated above. In a small number of cases, animals react upon external stimuli by changes of colour. Since an animal showing this peculiarity is fairly common in this country and probably known to you, I will mention it here. It is the chameleon (*Chamaeleo basiliscus*, Arabic حربايه). The creature when undisturbed appears of an almost uniform sand- or dust-colour; but when you irritate it for some time this colour will soon change into irregular black patches on a bright yellowish background. When left alone for a short time the animal re-assumes its original colour. In this case, therefore, the organism reacts upon the irritation by a change of colour. To avoid misunderstandings, I must, however, state that movements of certain minute parts of the body are at the bottom, even of these changes; how, I shall explain later (p. 74). As I have said, irritability, although we cannot actually demonstrate it everywhere, is very probably present in all organisms; you will also notice its very close connection with mobility.

There now remains a last characteristic of organisms, and this is "**Reproduction**". The word means that the organisms are able to "produce" certain parts which sooner or later become detached from the body and gradually assume the same shape as the organisms that produced them; in other words, that every organism is able to "re-produce" its own race. It is a well-known fact that no organism lives for ever; its life-span is limited and at some time it must cease to live. Before doing so, it produces an "offspring" which grows up, and in due time perishes, but, before doing so, again produces a new generation, and so on. There is thus a constant coming and going; the individuals die, but the race remains, represented by ever new individuals. The manner in which the various organisms reproduce their race, though identical in principle, shows many interesting modifications in detail; the particulars will occupy a good deal of our later discussions.

Reviewing now what we have thus far seen, there are seven distinctive characters by which organisms differ from anorganisms: Feeding, Respiration, Excretion, Growth; Movement, Irritability; Reproduction. So long as an organism "lives" these functions are exercised, whereas, when they cease to go on, the organism also ceases to "live", i.e. "dies". There is, however, still a very important difference noticeable between the several individual functions. Speaking of the human organism, with which you are the most familiar, we may imagine that a man can live without being able to move, that he can live without noticing outward stimuli, and without propagating his race. The surgeon frequently produces the two former states artificially, in order to prevent his patient from feeling the pain caused by an operation and making reactive movements. But we can not imagine that a man can live without feeding, or without respiring, or without excreting. As a matter of fact, he can not, and therefore these last-named functions are of much more immediate importance for the maintenance of life than those previously mentioned. Each of them, if it is stopped for some reason or other, must cause death, and if it becomes seriously interfered with, is a serious menace for life. The reason is that, as we put it in scientific language, they stand in "**Correlation**" to one another, which means that neither is really independent; **all** being, on the contrary, **inter-dependent** in such a way that each function must go on normally in order to enable the others to do the same, and can itself go on normally only so long as the others practically do the same. You will perhaps understand this correlation more clearly if you remember the steam-engine which, if taken as a whole, will also work satisfactorily only if all its parts work satisfactorily. As in an engine, e.g. the best fuel and the best air-supply do not help much if the chimney does not function, and as, in another case, the best chimney and the best grate are of no use if the fuel is unsatisfactory, so in the organism, also, life, which is the combined result of all its vital functions, is impaired if any of the functions is interfered with. You are going to study the diseases of the human organism later; you will then learn that there are indeed a number of diseases which immediately interfere with feeding, or respiring, or excreting. You will understand even now, before knowing the diseases themselves, why they are dangerous from the beginning, and sooner or later must lead to death.

Movement and irritability are far more conspicuous in animals, and therefore at first sight appear to be characteristic of these, though we have seen above that they are by no means absent in the plants. To the earlier observers and their more primitive methods of research this latter practically seemed to be the case, and they thereupon spoke of mobility and irritability as of particular "**Animal Functions**", in contradistinction to the others which they described as "**Vegetative Functions**". The terms, on account of their convenience, are often used even to-day, although of course they no longer imply any difference in the distribution of the two groups of functions.

After what has been said above we may define "**Death**" as "the cessation of the functions of life". When it has occurred, the body of the organism undergoes "**Decomposition**". It loses its shape; the substance, at first of a more or less solid consistency, becomes altered, usually liquefied, while a bad smell emanates from it. In the end, all the soft parts disappear, and only the hard parts remain; but even these become decomposed later, with the sole exception of inorganic substances which may have been contained in them. I will add that the special way in which the process of decomposition goes on varies very much with the accompanying circumstances among which temperature, access of air, and moisture, play the most prominent part (see also pp. 275 and 302). In very warm and dry air, smaller organisms in particular may become perfectly dry before decomposition has advanced very far; they may become "mummified", as we scientifically call it. But sooner or later, especially when the air becomes moist again, decomposition goes on as described above.

CHAPTER II.

On the Structure of the Animal Body : Systems, Organs, Tissues, Cells.

Division of Labour. — Functional Adaptation.

In order to make you understand what follows as best I can, I will deduce what I have to show from our own body with which I suppose you are best acquainted.

Man is an organism; as such, he performs the functions of life, that is to say, each individual man grows, respires, feeds, and so on. But when you look at the structure of the individual you already know enough of this to realise that the various parts of the body do not take an equal part in the performance of the various functions. Our eyes, our legs, our skin, for instance, have nothing to do with feeding. Everything connected with the process of nutrition is done by a special part of the body : the nutritive or " **Digestive System** ". Moreover, this system does not only the whole work of nutrition : it is also the only part of the body concerned in the preparation of the food.

We see absolutely the same with regard to respiration. Legs, eyes, and also the digestive system, do not take any part in the process of respiration. This function, again, is performed by a special " system " : the " **Respiratory System** ", which, in its turn, does nothing but respire. What you see with regard to the processes of nutrition and respiration is realised in essentially the same manner for the remaining functions of life ; excretion is carried out by the " **Excretory System** ", reproduction by the " **Reproductive System** "; irritability and movement are respectively peculiar to the "**Nervous**" and the "**Locomotory** * **Systems**".

Our analysis of the structure of the human body thus yields the result that this body, although biologically a unit, or entity, of its own, and as such performing all the functions of life, is yet structurally not a unit but composed of a number of parts — " systems"— each of which performs one of the functions for the benefit of the whole rest of the body. This fact is the outcome of the working of a principle, of fundamental importance throughout the world of organisms, namely the principle of "**Division of Labour**". I have pointed out in the preceding chapter (p. 8) that the performing of the different functions requires a certain power on the part of the organism, that it is for it a "labour". Let me recall in this connection the well-known fact that, after a meal, you usually feel "tired". After the meal, the digestive system begins its particular work; the power necessary to perform it is in part borrowed from the other systems and quite especially from those the work of which is not of immediate vital importance, viz. from the nervous and locomotory systems. That is why you feel "tired". The organism thus has to do "labour"; but it does not perform it in such a way that every part of the body carries out a part of every function, but the labour is "divided", and "distributed" among the different systems, in the manner we saw above.

It is interesting to note that this principle of "Division of Labour", as it governs the world of organisms, also governs our public and private life. It will perhaps help you to thoroughly understand it, if I show you by an example how it works in the latter case. A rich man usually has a big household which requires a good deal of labour to keep it properly running. To mention a few details: there is cooking to be done; the furniture, the plate, the wardrobe, the linen, must be looked after and kept in order; the entrance must be guarded; the garden must be attended to, etc. All these separate businesses, together, form the work of keeping the household running; in order to have it done, the master of the house engages servants and distributes the work among them in such a way that each servant gets one "department" to look after, but has nothing to do with the other departments. I think you see without further explanation the parallel which exists between this household and the individual organism; you see how identical in both is the effect of the "Division of Labour".

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* From the Latin "locus"—place, and "movere"—to move; "locomotion" being the technical term for every movement from the spot.

However, on reflecting a little further, you will find that such a division is necessary only for a big household. In the house of a poorer man the work to be done, though of the same nature as in the big household, is less in amount and may therefore be carried out by one servant, or perhaps, no servant at all is wanted, and the work is done by the master of the house and his wife alone; there is no necessity for forming "departments". On the other hand, even our modern states represent "households", but are households of the largest imaginable extent, in which the "household-work" is as considerable in amount as it is different in description. We accordingly find in a state not only departments, but see that these are divided and subdivided again, each section being entrusted with a particular portion of work and comprising a proportionate number of officials to do that work. I think I need not go into further details;

the examples quoted will show you that the necessity of a division of labour increases with the size of the household and with the amount of the work which is required in order to keep it properly running. You may conclude from this observation that something similar might exist also in the world of organisms; we shall indeed see later that there are quite a number of small and lowly organised creatures with scant vital activity, in which the principle of division of labour just begins to make its action visible (e.g. p. 103); from these, there are all possible transitions to those large and intricately built forms in which all vital functions are at their height, and which accordingly show the working of the principle in its full perfection.

The instance of the household may serve to make you understand another principle of fundamental importance, intimately connected with that of the division of labour. If the master of the house requires, for example, a new gardener, he will not advertise for a "servant", but for a "gardener"; he wants a man who, by experience and training, is especially fitted to do just that particular kind of work which is indicated by his name. The reason is that, owing to the work having been "specialised", i.e. having been split up into a number of different branches, the men have "specialised" their learning too, i.e. have prepared themselves for doing only one particular branch of work in place of the whole.

It is easy to see that this specialisation of the learning must go parallel with the specialisation of the work. As the work of a small household is little specialised, it requires no particular knowledge and can satisfactorily be done by a servant without special training. It is different with the intricate household-work of a state. Here, a member of any department must be cognisant not only of the general business incumbent upon his department, but more particularly of the special share he has himself in it. The separation of the departments and their subdivisions in a state thus leads to the formation of a corresponding number of branches of learning which more or less differ from one another. Our modern states indeed possess, besides the ordinary schools, quite a number of special schools in which young people are instructed in these different branches. Such schools were entirely unknown in earlier times and are absent even now in less advanced states; but their mere existence is proof that they are of advantage for the whole. For it is not difficult to understand that, in a state as well as in a household, a man who is specially prepared for doing a certain work, and has nothing to do but that work, can do it much more thoroughly and effectually than another who is not particularly trained and perhaps has additional duties, being thus obliged to divide his energies, and possibly even to neglect one part of his different duties for another. The advantage, further, will be the greater the more each individual servant, of whatever description his office may be, subordinates his personal interests to those of the whole, and works in the interest of the whole. While the human states, owing to the very human nature of Man, still are, some more, some less, far from such an ideal condition, Biology teaches that there exist animal states which come very near it (see p. 190), and that in a certain sense the living organism even is an ideal state (p. 42).

I have mentioned the above details because they are to exemplify, and help in explaining, conditions we find in the organisms. What interests us in the present place is that the specialisation of the work to be done in the human households and states necessitates a corresponding specialisation in the training of the persons who have to do the work. For this is simply the counter part of a principle carried through with rigid consistency in the world of organisms and called the principle of "Adaptation to the Function" or, somewhat shorter, the principle of "**Functional Adaptation**". It says that any organism, or part of an organism, which has a particular work to do, also exhibits a structure which seems particularly **suitable** for doing that work.

In accordance with this principle the "systems" of the human body also show functional adaptation; since, however, you have as yet no knowledge of their structure it would be of little use to bring forward details; but the point will incidentally be returned to in the sequel. In the meantime, let us continue our analysis of the human body which is not yet finished; in order to make myself understood as best I can I will deduce what I have to say from the **digestive system**, the structure and function of which are presumably more familiar to you than those of the other systems.

Let us first consider the actual facts observable in the process of feeding. We know that its general aim is to transform the original food into a mass containing the particular materials for the production of energy, or growth, as the case may be. For this purpose the food, for the greater part of solid nature, is first mechanically ground into small pieces — in many cases after having been torn off from some larger piece. The small pieces are acted upon by chemical reagents which dissolve them and transform them into the fluid substances capable of being utilised by the body. These substances, at first contained in the intestine, in order to be absorbed, must pass through the intestinal wall, while the waste products, i.e., those which cannot be absorbed, are finally removed.

These are the main "**acts**" of which the total process of nutrition is composed. If we now look at the "system" which has to carry out the work we at once perceive that it is composed of a number of **parts**, different in shape and arrangement, but exactly corresponding to the "acts" in the process. The tearing off and mechanical grinding of the food is done by the mouth with the help of teeth and tongue; the mouth is followed by a tube, the gullet, or oesophagus*, which hands the ground food over to the stomach where the liquefying is done; the stomach itself producing the necessary chemical reagents. Some further reagents required for the transformation of the food are supplied by certain glands (liver, pancreas) which open into the alimentary canal shortly beyond the stomach; the absorption of the liquid materials is done in the small intestine, and the refuse-products, instead of being constantly evacuated in small quantities (which would lead to obvious inconveniences for the organism) are collected in the large intestine in order to be given off in larger quantities at intervals. I hope you already know enough of the structure of the alimentary canal to realise that this picture is correct. If so, you will see that, within the limits of the digestive system, we again see the principle of division of labour in action; as the work to be performed is composed of a number of single acts, so the system which has to perform the work is divided into a number of parts, each of which is charged with one act, and with this alone. For the teeth, the tongue, or the gullet, have as little to do with absorption, as the large intestine has to do with the liquefying of the food, and so on.

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* Oesophagus—in Greek οἰσοφάγος—literally translated, means to "carry, push, lead" (οἴσω, from φέρω) what has been "eaten, swallowed" (φάγω).

We will here call these parts of the systems "**Organs**"—from the Greek ὄργανον which means "instrument", "implement", viz. for doing a certain work. You will now understand why we call the creatures provided with such organs "organisms"; they all do some work, namely, feeding, respiring, etc., and for this purpose have implements: namely, the organs. I must mention here that the use of the word "organ" in scientific language is not in perfect agreement with the definition I have here given, inasmuch as it is often used in a much wider sense, often in a narrower sense. As a matter of fact, it is frequently very difficult in practice to make a sharp distinction between what we here call systems and what we call organs. However, for the sake of the present argument, I think that this distinction is helpful.

The various "organs" of the digestive system, in addition to their existence, are specially adapted to their function. The teeth are hard, in order to be able to tear and grind the food; the tongue is mobile in order to move the food while it is being chewed (try in this connection to chew a piece of bread without moving your tongue: you will find that it is not practicable). The stomach is wide and has numerous glands in its wall in order to treat a large amount of food at a time. The small intestine is long and thin, but has, at variance from all other sections of the digestive tract, on its inner surface an immense number of small leaf-like prominences, the so-called "villi", which serve to enlarge its surface, because, according to a physical law, absorption increases commensurately with the size of the surface through which it takes place. The large intestine is again wide, in order to be able to collect a certain amount of refuse and thus prolong the periods between the acts of evacuation. We thus see that, indeed, the various parts of the digestive system, in their shape and arrangement, show unmistakable relations to their particular functions—that they are "adapted to these functions".

Like the digestive system, all other systems of the body are composed of organs which owe their origin to the working of the division of labour. In order to round off the sketch given above I will here insert a few remarks about their structure and their function, so far as you may understand them at this early period. In accordance with the distinction of the vital functions into "animal" and "vegetative" functions (p. 22) we also speak of "**Animal**" and "**Vegetative**" **Systems** and **Organs.** Beginning with the animal functions, the fact of their intimate association in Man and animals suggests that the respective systems, i.e. the nervous and locomotory systems, will also stand in close connection with one another. This is indeed the case; speaking generally, the whole work they have to perform is distributed between them in such a manner that the reception of any stimuli coming from without and their conduction to the body is the province of the nervous system, while the movements made in response to the stimuli are the province of the locomotory system; in addition to this the nervous system has the very important function of conceiving decisions independent from external stimuli and inducing the locomotory system to make voluntary movements.

If knowing this function of the **Nervous System** we contemplate its structure and arrangement in the human body we cannot fail to notice that it is indeed admirably adapted to its function. In order to understand this let us remember, first, that the stimuli coming from without may be of very different nature (light, sound, temperature, and others); that, secondly, they may hit the body in very different places, and that, lastly, the responses of the organism may be different for one and the same stimulus and may be the same for different stimuli. To illustrate this latter point by an example: if strong light irritates us we may close the eyelids or we may shade the eyes by the hand, while we shut the eyes not only because of strong light, but also when they are irritated chemically (e.g. by acrid vapours such as ammonia) or mechanically (e.g. by particles of dust).

Under these conditions we ought to expect the whole nervous system to be made up of three different parts or "organs" in the sense above given, namely, stations for receiving the stimuli, contrivances for conducting them, and a central station in which the messages coming in from various directions are sifted and handed over to the particular parts which in any given case are called upon to respond. Such organs exist and bear the names of the "**Sense-Organs**", the "**Peripheral Nerves**", and the "**Central**", or "cerebrospinal" **Nervous System**. Further details of their structure and functions you will be taught in Anatomy and Physiology.

The "**Locomotory System**" brings about the movements of the body, both involuntary and voluntary. They are the work of certain organs which we call "**Muscles**", more or less elongated pieces of "flesh", which have the power of actively shortening their length, and by this "contraction" exercise a dragging force. There are many of such muscles present in the human body, but they would be of little practical use if there were not, in addition, certain hard parts to which they may be fixed, and the relative position of which they may change by contracting. These are the "**Bones**"; to properly value their significance, try to imagine them to be removed, say, from an arm, or a leg. The result would be that the limb not only loses its shape but becomes entirely unfit for any regular work. Muscles and bones, in spite of their large number, are therefore "organs" in our sense, i.e. products of a division of labour in the locomotory system: the muscles supplying the actual power, the bones the stability and resistance to transfer this power to the rest of the body.

As regards the vegetative systems (apart from the digestive apparatus) they will occupy us in greater detail in a later chapter (pp. 443ff); at this place a short preliminary sketch must be given of the structure and function of a system not hitherto mentioned. We have seen that the digestive system prepares the food for the whole organism. The prepared food is ready for absorption in the small intestine. But even when it has passed through the walls of the latter, it only is in its immediate neighbourhood. We know a number of small and simply organised animals in which all parts of the body lie in immediate neighbourhood of the intestine; in these animals it is easy for every part of the body to take from the surface of the intestine that amount of food material that it may require for doing its labour (see p. 421). But in Man (and the higher animals in general), the different parts of the body lie at very different distances from the intestine, and while it would be easy, for instance, for the kidneys, or the lower part of the vertebral column, to obtain their share of the food, it would be very difficult for the head, or the feet, to do the same.

On reflecting a little further we cannot fail to see that a similar difficulty exists with regard to respiration; for, though the respiratory system has to provide the oxygen for the whole organism it only introduces it into the lungs which are in fairly close contact with certain organs, but lie far away from others. Lastly, excretion is practically carried out solely by the excretory organs (in Man represented by the "kidneys"), although every part of the body, in connection with feeding and respiration, also produces waste-products.

In order to cope with all these inconveniences, the body of Man and the higher animals possesses a system entirely absent in the lower, the special task of which is to distribute food and oxygen to all parts of the body, while at the same time collecting their waste-products. This system is the "**Circulatory System**". Now let us see how its general structure tallies with the function. First of all, it consists of tubes, the "**Vessels**", which establish the necessary connection between the parts concerned. Secondly, it contains a fluid, the "**Blood**"; for only a fluid can carry, in addition to materials which are in themselves liquid, gaseous and solid substances in a dissolved condition. A fluid, further, can easily be moved; it is not difficult to see that in order to bring about a thorough distribution to even the most distant parts of the body the blood must be constantly kept in active motion. This is effectuated by a kind of "pumping station", the "**Heart**", the presence of which is a third point of evident harmony between structure and function within the circulatory system. These few details may suffice for the moment; a fuller account of some vegetative systems and their mutual relations will be found in a later chapter (p. 443 onwards).

If you fully understand the fundamental importance the circulatory system has for the proper working of the whole organism you will understand why a similar system is present also in the higher plants, although these, in their general appearance and structure, widely differ from the animals. We shall speak of the circulatory system of the plants in more detail later (pp. 267 and 339ff); at this place, I have mentioned its existence in order to point out to you, by a special example, a fact well-known from the world of organisms, namely, that for a similar purpose or a similar work to be done we find similar structures in organisms otherwise quite dissimilar.

We call such similar organs of different origin in comparative Biology "**Analogous Organs**". The term must not be confused with the somewhat similar term "**Homologous Organs**", which also frequently occurs in scientific language, but has a different meaning, in so far as it is used for organs which are different in appearance and function, but have the same origin, in fact represent the same part, as it were, in a varying "make-up". An example will help you to understand the point. Birds and butterflies (أبو دقيق) are capable of "flying", and for this purpose have "wings". But as the wing of a bird originates in a manner, and hence has an anatomical structure, quite different from a butterfly's wing, the two kinds of organs are "analogous" organs, just as the circulatory systems of animals and plants. On the other hand, the wing of a bird, although it serves for flying, and the foreleg of a horse, although it serves for walking, have the same internal structure as our arms which serve for grasping; indeed all three are the same organ modified in connection with a somewhat modified function. The wing of a bird, the foreleg of a horse, and the human arm, are therefore "homologous" organs.

The result of our discussion, thus far, is that the human body, although a unit biologically, is yet structurally composed of systems, and these, in their turn, are composed of organs. Systems and organs are products of a "division of labour" and, in their structure, show "functional adaptation". All we have mentioned is observable with the naked eye: if we use the microscope * and proper methods, we will find that the organs, again, are composed, and consist of various parts, which, again, owe their existence to the working of the principle of division of labour, and are each adapted to its particular function.

We have spoken above of the muscles. If we closely look at such a muscle with the naked eye, we notice that it is striated in the direction of its length ("longitudinally" striated); if we examine a piece under the microscope, the striation will be found to be due to the presence of very fine fibres lying closely packed together. These fibres alone have the power of contracting; the contraction of the whole muscle is due to their combined action. In addition to them, the muscle contains other elements which, for instance, separate the fibres into bundles, or envelop the whole muscle, but have nothing to do with contraction. The fibres are the essential constituents of every muscle; their particular shape is equally worthy of note. For it is clear that the form of a fibre is just that form most suitable for a part of the body which has to produce some power by contracting. Suppose you have two equal quantities of indiarubber, one in the shape of a ball, the other in the shape of a string. You will find that you can draw out the latter much longer than the

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* Greek, from μικρός—small, and σκόπω--to watch, observe. investigate: it therefore means a contrivance to "observe small things".

former, and therefore the effect produced by their subsequent contraction is larger in the case of the string than it is in the case of the ball.

When we look at the intestine taken out of a newly killed animal (e.g. a cow in the abattoir), we will notice that it makes slow movements of contraction and distension. These are the so-called "peristaltic" * movements which also take place during life and serve to move the intestinal contents slowly on towards the large intestine. Their presence indicates that there must be "contractile" elements in the wall, similar to the fibres of the muscle. This is indeed the case. If we examine the wall of the intestine, we find that even two sets of such elements are present, one set of fibres running in the direction of the length of the organ, the other set running transversely round it. The former, by their contraction, shorten the length but at the same time dilate the width of a certain portion; the latter, by their contraction, again reduce the width but increase the length. In this way the two sets of fibres act one against the other, each restoring the original condition changed by the other. We call such structures "antagonists" †.

What we have here seen with regard to the presence of fibres in muscles and in the wall of the intestine is true for all other organs of the body capable of making active movements; wherever there is contraction this is carried out by fibre-shaped elements (you will learn later that they slightly vary in their aspect, but this is of no consequence for our present discussion). These elements therefore evidently represent

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* Greek, from περί—round about, and σταλτικός—contracting, compressing.

† From the Greek ἀντί—against, and ἀγώνη—fight, contest.

a definite structural unit, which performs the particular function of contraction.

The human and animal bodies still contain a number of similar structural units, and the particular thing about them is that, under the microscope, each appears to be composed of a large number of **equivalent** parts, closely packed and united to one another by a kind of glue, or "cement", and that it has a special but **elementary** function. We call these units scientifically "**Tissues**". You may get a fair idea of their constitution if you remember the sandbricks made in this country. If you look at such a brick with a pocket-magnifying-glass you will perceive that it consists of grains of sand, all of the same substance and about equal to one another in shape and size, and united into a whole by a firm cement. If by some means or other you would dissolve that cement you would again obtain the isolated sand-grains, i.e. the "constituent elements" of the brick.

To return to the organism, all muscle-fibres therefore represent the "constituent elements" of a "tissue", the function of which is **contraction** and the name of which is "contractile" or "**Muscular Tissue**". The bones are chiefly (not entirely) made up of "**Bone-Tissue**"; the minute elements which compose it are very different in shape from those of the muscular tissue but they are similar to each other. They are in this case somewhat separated from one another by a very copious "cement" which is rather hard by itself but becomes still more so by the deposition in it of certain inorganic matter, chiefly combinations of lime. In fact, the particular function of the bone-tissue is to give stability and resistance. Wherever, therefore, in an organ these qualities are required bone-tissue is developed. The resistance may often be wanted for the protection of soft and sensible organs; to this circumstance the skull for instance owes its existence.

The bone-tissue, owing to its hardness, is very inelastic. It may happen that some organ, in order to fulfil its function, must be resistant, but elastic or flexible at the same time. In such cases, we find a tissue complying with these demands, the "**Cartilaginous Tissue**". I will mention as an example the windpipe or "trachea", connecting the lung with the outer world. It is of fundamental importance for the proper function of the respiratory system that this passage should be always open; at the same time, the trachea must not hinder the movements of the neck and must allow the passage of food through the gullet (which lies close to the dorsal aspect of the trachea). Under such circumstances, it is comprehensible that the wall of the trachea contains cartilage-tissue.

As I have said above, the body of Man and animals contains quite a variety of such tissues, the study of which has gradually developed into a particular science called "**Histology**"*. You are taught part of it (viz. the part referring to the tissues of Man and the higher animals) in separate lectures; so I can dispense myself from going into further details here; I will merely mention some other tissues and their functions. There is a "**Connective Tissue**" with the function of connecting various structures to one another (e.g. the muscles to the bones); there is a "**Glandular Tissue**" charged with the elaboration of certain fluids needed for certain purposes. We call the formation of these substances "**Secretion**"; you must not confound this with the "**Excretion**" spoken of above. Re-

* Greek, from ἱστίον—woven stuff, tissue, and λόγος. See p. 2.

member, therefore, that this latter term is used in the case of waste-products which are to be removed from the body, while the former is used in the case of useful products necessary for the body. Thus, the saliva, the bile, the pancreatic juice, are " secretions " produced by the " glandular tissue " of salivary glands, liver, and pancreas. I will finally mention the " **Epithelial Tissue** " which has the general function of covering the external and internal surfaces of the various organs, including the external surface of the whole body. This tissue, therefore, usually appears in the shape of membranes.

All the organs of the body are composed of such tissues; but the particular tissues which enter into the formation of an individual organ depend on the function of this organ. We have spoken above of the function of the stomach: it has to liquefy the food by chemical reagents (chiefly hydrochloric acid). Remembering this, we should expect to find in the stomach the following tissues: glandular tissue for the secretion of the acid; muscular tissue for moving the contents and mixing the food with the acid; epithelial tissue for covering the surface; connective tissue for connecting the various elements into a whole. These tissues are indeed present in the stomach; there are no bone-tissue and no cartilaginous tissue, nor are they required.

In defining what we call tissues I said that they are composed of a large number of minute, but equal elements closely packed together. In the case of the muscular tissue, these elements have the shape of fibrils; in the other tissues, their form is different: it may even differ to a certain extent in the same tissue, causing this to appear in different " varieties " which depend in part on slight modifications in the function of the tissue, in part on the nature of the organism in which the tissue occurs. In all cases, however, the particular aspect of the constituent parts of a tissue is so characteristic under the microscope that we **recognise** the nature of the tissue from the shape of its elements; on due consideration, it will also be found that this shape is in every case manifestly the result of functional adaptation. Further details must be left to your Histology-lectures.

The constituent elements of the tissues are scientifically called "**Cells**"*.

We have thus come to the result that the body of Man is composed of systems, the systems are composed of organs, the organs of tissues, and the tissues of cells. **The cell is thus the constituent element of the whole organism**, in a similar manner as the brick, e.g. is the "constituent element" of a building. For just as houses of very different size, shape, and internal arrangement may be constructed of bricks, so the bodies of very dissimilar organisms may be built up of the same constituent element, the cell. Anatomically speaking, we therefore find the cell at the bottom, as it were, of the structure of every organism.

We further know that the organism lives. The work connected with life is specialised in such a way that each system, organ, and tissue receive their special share to do, and indicate the nature of that share by their aspect. Considering, then, that the work done by the whole organism is only the sum of the special shares done by the systems, and the work done by the systems is again the sum of the shares done by the organs, and so on, we see that the work done by the tissues must be the sum of the work done by their constituent cells. We may now understand why the function of the tissues is so elementary and practically limited to **one kind of action** (as covering, connecting, secreting, etc.). For, as the constituent cells of a tissue are all equal in shape and appearance, there is **no division of labour among them**; they all do the same work, and their combined action represents the simple action of the tissue. The various tissues unite to form the organs, the organs unite to form the systems, and so we see, as a second important result of our discussion, that **the work done by the whole organism is the combined work of all its constituent cells.** We accordingly find the cell at the bottom of the functions, i.e. of the "life" of the organism, as we found it at the bottom of its structure.

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* Latin, from "cellula"—small case, small chamber.

But we will now also understand that the result of this combined work can only be satisfactory if **all** the cells do their duty, which consists in not only **doing** the work meted out to them, but also doing **nothing but** that work. If both these premises are fulfilled the organism is what we call "sound", and would in this condition indeed represent an ideal "state of cells" (p. 27). But it may also happen that certain of its "citizens" fail to do their duty; the consequence is invariably that disturbance in the functional equilibrium of the whole organism which we call "**Disease**". Every disease is ultimately a deficiency in the proper working of the body-cells, either of all, or only of certain kinds or groups. We spoke on page 21 of diseases which have their cause in an alteration or total cessation of certain vital functions; in these cases the cells which compose the respective organs fail to comply with the first of the above conditions. You will learn in Pathology* later that another fairly frequent source of disease and death in Man are "tumors". From the general biological point of view they are the outcome of certain cells of the body failing to comply with the second of the above conditions, inasmuch as they change from their normal duties to a conduct which is positively harmful to the organism.

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* Greek, from πάθος—suffering, disease, and λόγος. See p. 2.

The fundamental importance which the cell thus has in the world of organisms is borne out by two other equally significant facts. When speaking of reproduction, we said that the organism "produces certain parts which sooner or later become detached from it" and grow to new independent organisms of the same kind. The parts here referred to, at the moment of their detachment from the body, are, in by far the greater number of cases, cells, so-called "reproductive" or "sexual cells". They gradually develop into new organisms, which thus have their starting point in a single cell. Even in those cases where the new organisms, at the moment of their detachment from the parent organism, have already acquired a comparatively large size and complicated structure (as, for instance, in the offspring of "viviparous animals"* and the seeds of the higher plants), they nevertheless have taken their origin from a single cell. **Thus every organism, as its body is made up of cells, and its vital functions are due to the vital functions of cells, also takes its origin from a cell.**

If this is true, then, the many cells which as we saw above make up the fully developed organism must have arisen by a multiplication of the original cell. We shall indeed see later that this is the case, and that the methods by which the cells multiply form an important chapter in general Biology. Their multiplication, i.e. their increase in number, is at the same time the cause of the increase in size, i.e. the growth, of the body. It is a fact of common experience that any organism grows most intensely so long as it is young, and its cells accordingly are young also. I may here mention at once that the capability of multiplying is essentially a peculiarity of young cells and becomes gradually lost when they assume their specialised shape and commence to do their particular work in the service of the whole. We shall have to remember this circumstance on various occasions later.

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* Latin, from "vivus"—alive, and "parere"—to bring forth, give birth to; the term therefore differentiates the animals which give birth to "living young" from the "oviparous" animals which produce eggs (ovum—the egg).

In addition to the larger animals and plants, the bodies of which are made up of innumerable multitudes of cells, we know smaller organisms in which the number of cells is accordingly less. We know even very small organisms, **animals and plants, which during their whole life never exceed the limits of one cell.** They show the characters of life, notwithstanding, and we here have the actual proof that the individual cell is capable of performing all those functions which, in the higher organisms, we find distributed over an enormous variety of different cells.

For all these reasons the cell has been called " **the Elementary Organism** ", i.e. the organism with the simplest structure we can imagine. It should not, however, be concealed in this connection that recent discoveries as well as logical deductions render it ever more probable that there are units of life lower than the cell. Interesting and important though the respective particulars may be, they go far beyond the range of these elementary lectures ; so we will begin our study of life with a study of the cell.

CHAPTER III.

On the Cell.

The organic cells were first seen shortly after the invention of the magnifying glass, at about the middle of the seventeenth century, in vegetable tissues (cork). Here, they have indeed a very regular, rectangular shape, and sharply marked walls, appearing in fact as minute "cases" or "chambers", as indicated by their name. The recognition of their true nature and their discovery in the animal tissues are of much more recent date (about 1840). Our present conception of the cell widely differs from that originally connected with the name, although this name has been retained; we also know that the various cells may present a very varying aspect in the different organisms and their parts. Nevertheless, there are certain characteristics which remain peculiar to the cell under all these varying circumstances, and these may be expressed in the following definition: The cell is a minute piece of "Protoplasm", which in its middle contains a smaller piece of a somewhat more refractive and apparently denser variety, the "Nucleus". There are, therefore, in each cell, two constituents of equal importance, and any structure, in which the one or the other is absent, is as yet still open to doubt as to its cellular nature. On the other hand, many cells, in addition to these two characteristics, may contain structures, or show peculiarities, which are very apparent, but are not distinctive of the cell, because they are not present in all cells. Thus a living cell presents the average appearance shown in Figure 3, a preserved and stained cell that shown in Figure 1, Plate I. We begin our special description with the protoplasm.

1. — PROTOPLASM *.

This is a very wonderful and mysterious substance, of the true nature of which we have as yet no precise idea. We only know certain of its peculiarities, and these are the following. **Protoplasm is the living substance.** Wherever there is a process of life going on, we see it tied to protoplasm. To our present instruments and methods, it appears to be the same throughout the world of organisms; but there is not the slightest doubt that it must be different in all the various forms of creatures, and possibly even in the various tissues of the same creature. The germinal cells of two kinds of animals may (and often do) appear absolutely alike to our eyes and our chemical reagents, and nevertheless the one invariably develops into the one form of animal and the other into the other. This fact is only explicable on the supposition that there are substantial differences in the protoplasm of every kind of organism, but in what they consist still remains to be found out.

Protoplasm "lives", and in doing so performs the functions of life, quite especially those three of which we saw on page 21 that they are of immediate importance for maintaining life (feeding, respiring and excreting). We do not as yet know how this work is carried out, but the obvious fact that it is carried out leads to some important logical consequences. If protoplasm constantly takes up nutriment and air, if it constantly transforms materials, and constantly produces waste-products, we must assume that it is itself in a constant **change**, or a constant "flux", the existing substance being gradually consumed by the activity, and new substance being formed in its place. This flux, indissolubly connected with the work of life, must naturally go on as long as life lasts.

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* Greek, from πρῶτος—the first, earliest; and πλάσμα (from πλάσσω—to form, mould, shape)—something formed, or to be formed, into a shape; you may approximately translate it "the earliest form", i.e. of the living substance, or also "the first formative matter", i.e. of organisms.

The end of life is death; we previously defined it "the cessation of the manifestations of life". Protoplasm, as the living substance, therefore ceases to "live" when it ceases to work. It suffices that for some reason **one** of the vital functions be stopped in order to arrest **all** the other functions. If this happens the flux also, which is going on in living protoplasm, is materially altered, finally entirely stopped. We thus see that not only does the flux of substance go on so long as life lasts, but life only lasts so long as this flux **can** go on without material alteration. The factors which may interfere with the work of the protoplasm may be very different. Most of them are "external", i.e. come from outside, but they may also be "internal", i.e. come from the protoplasm itself. It is a well-known fact that any organism with old age becomes leaner, weaker, less resistant. It is only logical to suppose that this is due to a decreasing power of the protoplasm, and an increasing alteration in the flux of substance, which finally lead to an entire cessation of life. In this consumption of the powers of the protoplasm by its own work, comparable to the wearing out of an engine after long years of use, we may see the cause of "natural death", i.e. of the fact that the life of every organism is limited.

However, what is particularly worth being kept in mind is that the "functions of life" and the "flux of substance" cannot be separated from one another, nor can they be separated from the conception "protoplasm". As soon therefore as the two processes are stopped protoplasm loses its one essential character, viz. of being the " living " substance, and thus logically must cease to be true protoplasm. In other words: Protoplasm is the only substance capable of living, and is true protoplasm only while living. We have means to preserve it after death in such a manner that even very minute details retain their shape and aspect; but nevertheless it is, in this state, no longer " protoplasm".

I presume that you experience some difficulty in understanding the essential character of the living substance which I have just tried to explain. So let us have recourse to a comparison. You know that a " fire " is a process of combustion producing energy which becomes perceptible to our senses in the shape of " flames ", i.e. a combination of heat and light. The flames present about the same appearance so long as the fire burns, and yet the actual particles of fuel and oxygen which by their union produce them are renewed every instant. They go into the "fire" in a certain form and leave it in another after a few moments, while the changes they undergo during these moments bring about the phenomenon of the " fire ". In a similar manner we have to imagine that food and oxygen enter the living substance, that within this their combination releases the forces which appear to us as the " manifestations of life ", and that the products of the combination leave again as waste-products. The essential feature of both the fire and "protoplasm" is the process going on in the substance with which we see them associated: and in order to keep this process going on both must be constantly supplied with ever fresh materials. In the fire we clearly see that it suffers when irregularities occur in the supply of fuel and oxygen, and that it ceases to be a "fire", when the supply of one factor is stopped. As the cold, half-burned fuel which remains surrounded by the oxygen of the air is no longer the actively burning " fire ", so also " protoplasm " is no longer the " living substance " when the vital process going on in it is stopped.

Apart from the essential **biological** character which I have here attempted to explain, protoplasm shows a number of physical, chemical, and microscopical peculiarities.

Physically considered, it is a colourless substance, in the main resembling the albumen of a hen's egg. It is just hard enough not to flow asunder as a fluid does when in contact with some solid object, and it is just soft enough to easily change its shape ; we call it " plastic " *. It is by itself transparent, or semitransparent, but often rendered more or less opaque by fine granules deposited in it. It is not soluble in water, but slightly heavier than this, and refracts light somewhat more strongly. When heated to about 55° centigrade it "**coagulates**", i.e. passes over into a somewhat harder state which has lost plasticity and transparency. Actual freezing also kills it, without, however, noticeably altering the plasticity and transparency. The reaction of protoplasm is usually alkaline, sometimes neutral, but never acid.

Chemically, it is not a combination but a **mixture** of various different substances. The most important among these are highly complicated compounds of carbon, oxygen, hydrogen, nitrogen, and sulphur, called **proteids** ; besides, compounds of proteids with phosphorus, iron, or other metals are usually present. Owing to this composition, protoplasm is combustible; in the beginning of the process it develops a variety of gases which by their bad smell indicate the presence of sulphur or phosphorus (just as do the gases emanating from decomposing protoplasm). After combustion, protoplasm leaves a small quantity of ashes in which, besides the above-mentioned metals, potassium, sodium, and other elements, may be found. All living protoplasm contains a comparatively large amount of water. Weak acids coagulate protoplasm, whereas strong acids destroy and dissolve it; the same effect is produced by alkalies.

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* From the Greek πλάσσω—and meaning : capable of forming, or being formed into, various shapes. See also note on p. 46.

There are cases in which the behaviour of protoplasm somewhat deviates from the description just given. Although usually a comparatively large amount of water is required to keep it alive, we yet know a number of lower animals which may become completely **dry**, and remain so for a considerable lapse of time, without losing their vitality. So long as they are dry they seem to be dead, but when moistened again they swell to their former shape and live as before. A minute animal common (in Europe) in mossy * earth permeated with organic debris, has for a long time been a famous example of this peculiarity, and, from it, has directly received the scientific name *Macrobiotus* †. To-day we know the peculiarity in a variety of different organisms, some of which may even undergo the process of desiccation and resurrection several times without suffering any damage. We observe a resistance to dryness also in the seeds of the higher plants. It is a fact familiar to you that a grain of corn, or a bean, at first soft and moist, become hard and dry when "ripe", and remain so for years. But when you place one in moist earth, it at once begins to take up water and to sprout, and finally develops into a new plant. It has been alive all the time, though only in a state of "latent life".

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* About "Mosses" see p 318.

† Greek, from μακρός—large, long, and βιόω. See p. 2.

But place a bean, while dry, in an atmosphere of chloroform, or heat it to about 60° centigrade, for about twenty-four hours, and it will not sprout; it has been killed by the treatment, as any other organism would have been if treated in a similar manner. There are certain most wonderful exceptions even to this rule. The spores of some bacteria (you will learn what these are in Chap. X, 2; p. 305) are capable of remaining alive even if exposed for some time to temperatures as high as 105° centigrade.

As a consequence—in part at least—of its physical and chemical qualities, protoplasm shows two peculiarities which are of the utmost practical importance for our scientific studies. They are (1) that protoplasm may be "fixed" or "preserved", and (2) that it may be "stained". We have already mentioned that certain reagents coagulate protoplasm and thereby of course kill it. But some reagents do that killing and coagulating in such a way that the shape and minute structure of the substance do not apparently become greatly altered. Since, further, coagulated protoplasm is much more resistant and durable than living or non-coagulated, "**Preservation**" becomes a valuable means for our studying the various protoplasmic structures. You know that, by boiling, we can coagulate a hen's egg. If we leave a boiled and a non-boiled egg exposed to the air we will notice that the latter becomes decomposed much quicker than the former. Whereas, further, if taken out of the shell, the raw egg at once loses its shape and even becomes perfectly destroyed, the boiled egg retains its original arrangement; we may cut slices of it in every direction, and thus see the shape and the relative position of the various parts. However, to obtain this result, we must preserve the egg while it is still fresh; if we take for our experiment an egg already more or less advanced in decomposition, preservation will not help us very much, because it only "fixes" the substance in the state it has at the moment of preservation but never restores the original condition. This is a point sometimes overlooked by investigators. Any specimen, therefore, will show "natural conditions" only if it has been preserved immediately after death, or better still, if the protoplasm has directly been killed by the preserving reagent. Such reagents we know in large number; the chief are certain weak acids and solutions of certain mineral salts; in some cases also alcohol is useful; more particulars you will learn in your Histology classes.

The second important peculiarity of protoplasm, especially in the preserved condition, is its capability of **taking up stains**; under certain circumstances, non-preserved, and perhaps even living protoplasm, are capable of doing the same. We are not as yet perfectly certain about the nature of the process; it is also probable that it is not in all cases identical. The fact, however, remains that if we place preserved protoplasm in solutions of certain coloured substances, it imbibes these and then appears equally coloured throughout with the substance chosen. If we now place the specimen into a portion of the fluid in which the colour was dissolved, this again withdraws it from the specimen, but not totally; for, if we examine the specimen subsequently we will find that different parts of the protoplasm have retained the stain in a different degree, there being darker-stained structures among others which are less dark (Fig. 1, Pl. I). We call the latter part of the process described "differentiation of the stain", as indeed it is a valuable means to differentiate certain protoplasmic structures from others. We shall have to say something of these structures presently.

If we examine living protoplasm **under the microscope** it appears, as already stated, either quite homogeneous * and hyaline †, or slightly opaque owing to the presence of granules contained in it. Not infrequently, these are limited to the central area of the cell, leaving a broader or narrower peripheral area free; we differentiate in this case an "**Entoplasm**" from an "**Ectoplasm**" ‡. Apart from these optical differences the granular entoplasm is, physically, usually somewhat softer and more liquid than the more viscous ectoplasm. When a living cell, while being observed, begins to die, our highest powers of the microscope faintly show, even in quite hyaline and transparent protoplasm, a minute structure. There appears a very fine network of apparent fibres of somewhat darker shade upon the light background of the remaining mass. As these fibres to some extent resemble those of a sponge, the substance they consist of has been given the name "**Spongioplasm** §", while the lighter modification of protoplasm filling the interstices between the fibres is called "**Hyaloplasm** **". The whole structure becomes more clearly visible in preserved and stained protoplasm (*Pl*, Fig. 1, Pl. I); in the latter, the fibres are even found slightly darker stained than the rest. The average diameter of the meshes remains below one micromillimetre *; all coarser fibres, or meshes, are therefore not parts of this structure. As to the nature of this net-work, we have several theories, two of which may here be mentioned.

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* Greek, from ὁμός—equal, similar, and γενεά—origin, nature, kindred. The contrary is "heterogeneous" (ἕτερος—other, unequal). Clear ice, for instance, is "homogeneous," i.e. of "equal nature" throughout; but as soon as it encloses minute air-bubbles (as you often see in artificially made ice) it ceases to be "homogeneous" and becomes "heterogeneous"—not of equal composition throughout.

† Greek, ὑάλινος—glassy, from ὕαλος—glass.

‡ Greek, from ἐντός—inside, inward; ἐκτός—outside, outward.

§ Greek, from σπόγγος—sponge, and πλάσμα, see p. 46.

** Greek, from ὕαλος, see above †, and πλάσμα.

According to a number of observers, the apparent fibres are true fibres which in their entirety compose a framework similar to that of a **sponge** (Fig. 2*b*, Pl. I). You may get an approximate idea of the constitution of the protoplasm as suggested by this theory if you imagine an ordinary bath-sponge soaked with water. The horny substance of the sponge supplies the framework of fibres, while the interstices are filled with a second more liquid substance. This latter would be continuous throughout the whole mass, as it is only traversed by fibres. According to the other theory, the apparent fibres are in reality the optical expression of delicate lamellae, and the protoplasm, instead of a spongy, exhibits a **foamy** structure (Fig. 2*a*, Pl. I). In order to obtain a clear idea of this, you may remember the foam of soap. This consists of minute air-bubbles, each surrounded by a thin membrane of soap-solution. In an isolated state these bubbles are perfectly round; but when they aggregate in two the partition-wall between them becomes flattened; if three or more join their walls become perfectly angular at the places of contact; not more than three join together at one point (Fig. 2*a*). You may easily convince yourselves of these facts by observation. In protoplasm, the meshwork of lamellae would be represented by the spongioplasm and the substance filling the bubbles by the hyaloplasm. You see that, in this case, the latter would not be continuous throughout the whole mass, as each bubble is surrounded on all sides by the lamellae of the spongioplasm. The theory of the foamy structure of the protoplasm has been specially supported by the fact that it is possible to artificially bring about similar structures by thoroughly shaking some sticky oil (olive oil) with watery solutions of certain salts (potassium-carbonate). The "artificial foams" produced in this way indeed resemble the structure of the protoplasm to a great extent.

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* This unit, very often used in scientific measurements and abbreviated by the Greek letter "μ", is the thousandth part of a millimetre; $1\ \mu = 0{\cdot}001$ mm.

2.—Nucleus [*].

The nucleus, unknown to the earlier observers of the cell, was discovered in 1833 in vegetable cells, but has since then been found in all other forms of cells, and is at present recognised as an integral part playing an important and very definite role in the life of each cell. Of course it consists of protoplasm, but the varieties contained in it differ in some respects from those in the body of the cell.

In modern "Cytology"[†], the protoplasm composing the nucleus is distinguished by the name "**Karyoplasm**"[‡], from the protoplasm composing the body of the cell, which, in contradistinction, is called "**Cytoplasm**"[§].

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[*] Latin, originally designating the edible inner part of nuts, but later used for all the various forms of seeds contained in the various fruits.

[†] The science which specially studies the cell. From the Greek κύτος which means the same as the Latin "cellula" (see p. 41) and λόγος (see p. 2).

[‡] Κάρυον is the Greek equivalent of the Latin "nucleus"; Karyoplasm therefore means "protoplasm of the nucleus".

[§] Formed, after the fashion of the preceding term, from κύτος (see above note †) and πλάσμα.

In many cells the nucleus is visible during life; appearing sometimes, viz. if it contains a comparatively large amount of fluid, in the shape of a clear, hyaline vesicle (Fig. 3, Pl. I), sometimes, viz. if it contains comparatively little fluid, in the shape of a somewhat darker, granular body (Fig. 8*a*, Pl. I). In other cells, it is not visible during life, but begins to slowly make its appearance when the cells during observation gradually die; it is rendered at once recognisable with great clearness when the cells are treated with preserving reagents. It usually lies in the centre of the cytoplasm and has itself an almost spherical shape. From this latter rule, however, many deviations may occur. There are cells in which the nucleus assumes an elongated, sausage-, or even horseshoe-shape; in some of these it may present a number of constrictions at regular intervals, exhibiting a resemblance to a chaplet, or rosary. In still other cells it may be ramified[*] (Fig. 6, Pl. I), or present a variable, more or less irregular shape (Fig. 8*b*, Pl. I). Each cell, as a rule, has one nucleus only; but, here again, exceptions may occur. There are cells which usually contain two or three nuclei, and others which enclose a large, sometimes very large, number; such cells are scientifically called "multinuclear", or (less properly) "polynuclear"[†] (Fig. 2, Pl. IV, Fig. 12, Pl. XX). In the cases hitherto mentioned the nuclei are all of the same aspect and of the same biological value. In a certain class of "unicellular"[‡] animals, of which we shall have to speak in some detail later, there are, however, very constantly two nuclei present which differ in size and aspect, and obviously also have a different biological value for their owners. Details of these you will hear later (see p. 99). The size of the nucleus, or the nuclei, also varies within wide limits in various cells. There are such in which the nuclei are so small that particular attention is required to see them, and others which have nuclei of considerable dimensions.

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[*] From the Latin "ramus"—branch, twig; therefore means: divided into branches.

[†] "Multus", in Latin, and πολύ, in Greek, meaning both: many.

[‡] "Unus", Latin word for "one"; therefore: animals consisting of one cell only.

The most essential and characteristic peculiarities of the nucleus are supplied by the substances of which it is composed. What the true nature of these and their arrangement during life is is difficult to say, because most of them can only be studied in preserved and stained nuclei—remember what we have said above about the differences between dead and living protoplasm. However, the facts brought to light by these investigations are clear and suggestive enough in many respects.

If we examine a preserved and stained cell under a low power, the nucleus stands out as a darkly coloured dot from the less coloured protoplasm of the cellular body (*N*, Fig. 1, Pl. I). If we use a higher power of the microscope we will notice that this dark colour is not uniformly distributed through the whole nuclear mass, but tied to certain structures which may somewhat vary in their arrangement. As a rule, we will see a network of irregularly branching, thinner or thicker, fibres (see Fig. 1); the substance they consist of is called "**Chromatin**" * — from its particular affinity to stain—or "**Nuclein**" — from the fact that it represents the most characteristic constituent of the nucleus. The chromatin in certain nuclei appears in the shape of small irregular granules attached to threads of a colourless substance (*Cr*, Fig. 5, Pl. I); the latter

* Derived from the Greek χρῶμα—colour, stain.

is usually called "**Achromatin**"* or, also "Linin". Between these chromatin-fibres, and occasionally adhering to them, we will find one or (more rarely) several small round bodies stained with equal intensity, but usually showing a somewhat different shade of the colour. They may frequently be seen in the shape of brilliant but colourless spherules (= small balls) even in the living nuclei (where indeed they were first discovered; see Fig. 3, Pl. I), and are known under the name "**Nucleoli**" (Singular: Nucleolus = small nucleus; *n* in Figs. 1, 5, Pl. I). The substance of which they consist differs from true "chromatin" in various respects and is called "**Paranuclein**" or "Pyrenin"†. The interstices between the chromatin-fibres are filled with an apparently liquid modification of protoplasm, which stains only slightly and is called nuclear "sap". In certain conditions of the nucleus this sap is very copious, and the whole nucleus then has a considerable size, while the network of chromatin-fibres is clearly visible; in other conditions of the nucleus the sap is more or less absent; then the nucleus is small and appears as an almost uniformly stained mass of chromatin (e.g. Fig. 8*b*, Pl. I). In addition to the substances here mentioned, there are several others present in the nucleus; since, however, they are of apparently lesser importance, I will not mention them here. The chromatin in particular plays a most interesting part in the reproduction of the cell, as we shall see later.

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* From ἀ (see p. 4 *) and chromatin.

† The Greek preposition παρά, in its various constructions, has a somewhat various meaning which, however, usually is some modification of "besides". In scientific terms, you may nearly always appropriately translate it "some other form of"; Paranuclein therefore means "some other form of Nuclein".

Pyrenin, from πυρήν—grain, granule, is the substance of the "granule" represented by the nucleolus.

3.—Centrosome *.

The discovery of this structure is comparatively recent. It is an extremely tiny body just visible under the highest powers of our microscopes and lies somewhere in the protoplasm of the cell, in most cases in the neighbourhood of the nucleus, sometimes close to it in an inward curvature of its wall. Occasionally it is easily recognisable by a fine radial striation starting from it, and running into the surrounding protoplasm (*Ct*, Fig. 1, Pl. I). It does not stain except with certain acid colours, and has thus far been demonstrated as constantly present only in some particular cells (lymph-cells, epithelial cells) of various animals and in the cells of certain lower plants. In numerous other cases it makes its appearance solely at the time of reproduction, but completely disappears from view after it. This has led to the suggestion that during the period of absence it is hidden in the nucleus, of which it actually forms a part which has wandered out into the protoplasm of the cell. Further revelations as to its nature and its whereabouts during the period of apparent absence must be left to future investigations; the probable significance of the centrosome will be inferable from the facts discussed on pp. 108ff and 178.

Recent investigations have revealed the existence of an additional number of special structures, as well as of interesting functional relations between the different constituent parts of the nucleus and the cytoplasm, in various cells of the animal body. They can I think here be left out of account the more easily as we are not yet sufficiently informed about their general biological significance.

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* Greek, from κέντρον—centre, and σῶμα—body, trunk.

CHAPTER IV.

On Life as Observable in the Lowest Representatives of the Animal Kingdom.

We now turn to a study of the manifestations of life observable in the cell. It has already been pointed out that there exist quite a number of "unicellular" organisms, the bodies of which consist of one cell throughout their life. As living creatures these cells must perform all the functions of life; but it may be anticipated that, here, these functions appear in their simplest form and are thus more easy to observe and more easy to comprehend than in the complicated higher organisms. We begin our studies with some unicellular animals. They exist in nature in an enormous variety of different kinds—as we scientifically express it: different "species"—all recognisable from one another by certain quite definite peculiarities of their own. In science, we combine all unicellular animals into a "Type", or "Phylum"[*] of the animal kingdom and call them "**Protozoa**"[†], in contradistinction to the "**Metazoa**"[‡] or multicellular animals. Every unicellular animal is therefore "a Protozoon", or a member of the "Type Protozoa", or the "Phylum Protozoa". The first we have to investigate more closely is "Amoeba"[§].

1.—Amoeba (Plate II).

The various species of Amoebae are small animals of an average diameter of thirty micromillimetres and live in moist surroundings; most of them in moist earth permeated with organic fragments, some in fresh water, others in salt-water, and a small number even in the bodies (chiefly the intestine) of various animals and Man. In this country they are frequently found in the muddy water of ditches and pools. They may be studied alive under the microscope; for the fact above mentioned that protoplasm is not soluble in water enables them to live in this medium, and the other fact that protoplasm is slightly more refractive than water allows them to be recognised in water in spite of their complete colourlessness. Looking at an Amoeba (Figs. 1, 2) you first notice the **protoplasm** of the body; it clearly shows the distinction into the granular entoplasm and the hyaline ectoplasm. In the former, certain species of Amoeba, in addition to the granules, contain a smaller or larger number of clear round spaces looking like minute empty bubbles (Fig. 2). We call such apparent bubbles in the protoplasm generally "**Vacuoles**" and a protoplasm which contains them in larger quantity "vacuolised"*. The **nucleus** is not easily visible in living specimens (*N*, Figs. 1, 2), but comes into evidence by preservation and staining. It then appears as an intensely coloured globular body surrounded by a halo of almost unstained substance (Fig. 4, Pl. I); the body representing in the main the chromatin collected into a compact mass, the halo the achromatin. This appearance of the nucleus is very characteristic of many Amoebae; also the vacuolised condition of the protoplasm is often very evident in preserved and stained specimens (Figs. 3, 4).

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[*] φῦλον. Greek,--family, tribe, nation.

[†] Πρῶτος—see p. 46, and ζῶον—animal; the science which studies animals in particular is thus "Zoo-logy".

[‡] From the Greek μετά—after: meaning the animals which come "after" the "Proto"-zoa.

[§] Greek; ἀμοιβός—changing, varying; Amoeb**a**—one Amoeba; Amoeb**ae**—several Amoebae.

These Amoebae, under the microscope, show certain manifestations of life. That which will strike you first is **movement**. When you see an Amoeba a few seconds after the preparation has been made the body has a rounded, slightly irregular outline. It is still floating in the water the preparation was made of, but being heavier than this, it gradually sinks to the surface of the slide. Amoeba is therefore not able to swim, or to float, but can move actively only on some solid support. When watching the rounded body for a little time after it has reached the surface of the slide, you will see that at one place (or several places) a slight outward bulging of the ectoplasm appears (*Ps*, Fig. 2); this will soon increase in size, and after some time also granular entoplasm will enter into it. It may, at this or any other time, be withdrawn into the body and other similar bulgings formed in its stead; but it may also continue to increase. If so, there will come a moment when the bulging has reached the size of the rest of the body, and if the process still goes on, the original conditions will be reversed, the bulging now representing the bulk of the body and the rest an appendage to it. The latter may finally be completely withdrawn; and when this is accomplished, the Amoeba has changed its place: it has advanced for a distance about equal to its own diameter.

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* Latin, from "vacuus"—hollow, empty.

Movements like those just described are going on almost constantly in every living specimen; they are specially lively in warm weather, but become slowed down, and finally entirely stopped, by a sinking of the temperature. In details they may vary considerably. There are species of Amoebae in which the formation of a bulging, its increase in size with concomitant entrance into it of the granular entoplasm, and the withdrawal of the rest of the body go on continually and so quickly that the whole body appears to "flow" in the direction of the bulging (so, among, others, in the species illustrated in Fig. 2). In this case therefore, the locomotion produced by the movements is very obvious. In other species, several or even many bulgings may be formed at a time (*Ps*, Fig. 1); they may be long or short, rounded at their extremities or pointed; most of them become withdrawn sooner or later, while one or the other increases in size and then leads to a change of place in the manner described. The body of the animal is thus, under favourable circumstances, in a constant state of change of shape, and hence the scientific name *Amoeba* (see here p. 60, §). The movements, although differing in the details alluded to, are all based upon the same principle, viz. the formation of bulgings and the gradual flow of the body-substance into them. From *Amoeba*, this sort of movement has received the scientific name "amoebic" or "**Amoeboid**" **Movement**; the bulgings, in the process of locomotion, to a certain extent play the part of feet, and are thence called "false feet" or "**Pseudopodia**"[*]. We find this amoeboid movement in a fairly large number of unicellular organisms and, besides, in certain cells of the bodies of higher animals; the white blood-corpuscles of Man are a well-known example.

While observing the movements of Amoeba, you may also convince yourselves of the irritability of the creature. It has already been mentioned that, immediately after the making of the preparation, its body is rounded, the pseudopodia not being sent forth till some time later. You may sometimes produce their new and sudden withdrawal by slightly touching the surface of the cover-glass with the point of a needle. The animal, by this contraction, reacts to the shock received by your action, just as the rounded shape it presented initially was the result of a reaction on the disturbance caused by the making of the preparation. You may, further, add to the water in which you keep an Amoeba the slightest trace of some irritating substance (as, e.g. an acid, or a solution of some salt), and it will withdraw the pseudopodia—it is indeed very difficult to "preserve" an Amoeba with these fully stretched.

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[*] Greek, from ψεῦδος—lie, deception, forgery, and ποῦς, ποδός—foot.

The pseudopodia still serve the Amoeba for another purpose. The medium in which it lives usually contains large numbers of other minute organisms, alive or dead, and, in addition, fragments of the broken-down bodies of larger organisms. These organic "débris" form the **food** of Amoeba; this food is therefore organic in nature. If an Amoeba, while creeping about in the fashion above described, happens to come into contact with such an organic fragment suitable for food, it "flows" over it and thereby transfers it into the protoplasm of its own body; as the technical term is, it "incorporates"* the food-particle. It is in this case of no consequence which part of the surface first touches the particle; as the surface is identical all round, every part of it is equally fit to incorporate food. You may get an approximate idea of the process by making the following experiment. Place some small object, e.g. a very small lentil, in the middle of a clean slide, and a drop of some slightly sticky oil near one of the short sides of the slide; then incline the whole so much as to make the oil slowly flow towards the lentil. There will come a moment when the oil just touches it; then, it will gradually flow all over it, and as soon as it has closed in beyond the lentil, the latter is practically within the oil—it has been "incorporated", as it were, by the oil. If you substitute the protoplasm of the Amoeba for the oil and the food-particle for the lentil you have the process of feeding as performed by Amoeba. If you keep the slide in the inclined position somewhat longer the oil will flow beyond the lentil and leave it again free, with the exception of an extremely thin film which remains behind and covers the lentil as well as the surface of the slide touched by the oil in its course.

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* From the Latin "corpus", genit. "corporis"—body; therefore: to take up into one's body.

If you examine a larger number of Amoebae, you are fairly certain to find among them specimens which contain food-particles in their protoplasm ; and if you have patience you may even watch the process of " incorporation " from beginning to end. Not infrequently, these food-particles are small regularly shaped bodies which, within a sharply drawn shell, contain some green substance ; they are tiny vegetable organisms (collected under the common name " Algae "), and especially suitable for what we desire to observe. In certain Amoebae, containing such green Algae, you will see (compare Fig. 1), on careful observation, that the granular entoplasm closes tightly all round the food-particles (the body to the left of the figure). In other specimens, you will see that, between entoplasm and Alga, there is a sharply marked space, seemingly empty, but in fact filled with a clear fluid (*fV*, Fig. 1). The size of this space may vary; if it is comparatively large, you may notice that the green colour of the devoured organism is fainter than it originally was, or is even almost entirely absent. Such blanched Algae may be found with small encircling spaces, or without any.

In the details here enumerated you observe the externally visible signs of **digestion** in Amoeba. When speaking of this process in general, we said that its chief " acts " are liquefying of the food, and absorption of the liquefied material (p. 28); the latter act is followed by the evacuation of the " indigestible " constituents of the food. In Amoeba, you do not see the process of liquefaction itself, but you see its results. The shell of the swallowed Alga is indigestible and therefore remains unaltered. But its organic contents are dissolved, as becomes manifest by the disappearance of the green colour and the accumulation of a clear fluid outside the shell. The Alga, at this time, seems to be contained in a "vacuole" which we call "**Food-Vacuole**" (*fV*, Figs. 1, 9). This is, apparently, not a permanent structure, for nothing definite of it is visible in Amoebae free from food-particles. If it is artificially produced by the liquefied food, we should expect the vacuole to again decrease in size as the nutritive fluid becomes absorbed; this it actually does until no trace of it remains and the entoplasm again closes tightly round the indigestible remains of the food. These remains, according to what we saw in the higher animals, have to be removed from the body. The same happens in Amoeba; it may still carry them about with it for a certain time, but in the end leaves them behind somewhere. This process of evacuation is simply the reverse of the process of incorporation and, in the main, goes on in the same way as the drop of oil, in the above experiment, gradually withdraws from the lentil. The only difference between the oil and the substance of the Amoeba lies in the fact that the former, being a fluid, leaves certain particles of substance behind all along its way, whereas the Amoeba consists of protoplasm which we know is not a fluid and keeps together even while it "flows".

The process of **respiration** is not outwardly recognisable in Amoeba; we can, however, convince ourselves, by experiment, of its existence and its necessity for the life of the organism. If we place a dish, containing in a small quantity of water numerous Amoebae, in a closed receptacle, and then remove all oxygen, the animals will all die after a short time; they are not able to live without this element.

Amoeba also **excretes**; the phenomena * connected with this function are not, however, observable with equal ease in all species of Amoeba. In the two forms depicted in Figures 1 and 2, we may, however, when watching specimens under the microscope with a high enlargement, discover in the entoplasm a vacuole similar to the food-vacuoles, but differing from them by its perfectly clear and transparent contents (*cV*; also seen in Fig. 9); it slowly becomes larger but, at a given moment, quickly shrinks and entirely disappears from view. Soon after, a tiny vacuole reappears at the same place; it slowly grows and when it has reached the size of the former vacuole, again disappears, to reappear in due time as before. This vacuole which, from its conduct just described, has received the name "pulsating" or "**Contractile Vacuole**", is the excretory organ of Amoeba. The fluid waste-products formed during the activity of the organism are collected in it, to be evacuated at regular intervals. It is interesting to note that the length of these intervals to a large extent depends on the temperature; being long in cold weather, but becoming much shorter in warm weather, an obvious proof of the fact that the processes of life go on with greater energy in higher temperatures but decrease in intensity as the temperature sinks. The evacuation of the excretory fluid apparently takes place through a part of the naked surface of the body, but is difficult to be actually observed.

Reproduction, in Amoeba (and many other unicellular organisms), may go on in several different ways. One of these is comparatively easy to study, because it is repeated at intervals of a few days, especially in warm weather and when the animals are supplied with a sufficient amount of food. The other modes are less easy to investigate, because they only occur—apparently at least—at certain periods and under particular circumstances. Their description, and the explanation of the pertinent illustrations (Figs. 5–8, Pl. II) must be postponed (see pp. 113 and 151); for the moment we turn our attention to the first mode which, from its chief feature, has received the scientific designation "**Reproduction by Division**".

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* See note † on p. 4.

When studying, under favourable conditions, a certain number of Amoebae, we are likely to come across specimens which at about the middle of their body show a more or less marked constriction, while others seem to consist of two halves connected with one another by a thin strand of protoplasm (Fig. 4). The specimens here characterised are in the act of dividing; they represent, as we scientifically express it, "stages" or "phases" * of the process of division. When systematically investigated (on living and preserved specimens) the process is seen to go on in this way. The first sign of an approaching division is given by the nucleus, which becomes somewhat elongated and, later, biscuit-shaped (Fig. 3). This constriction gradually grows deeper, while the two swollen ends of the nucleus move farther apart. There finally remains only a thin strand of nuclear substance between them; by its breaking, they become perfectly separated and only have to withdraw the tapering processes (by which they were thus far connected; Fig. 4) in order to regain their original shape and become independent nuclei. These, of course, only have half the size of the original nucleus. The phenomena observable in the protoplasmic body of the cell are essentially similar; the only difference is that they take place more or less later than the corresponding changes in the nucleus. In the end, we thus have, instead of the one original Amoeba, two, each of which represents about half of the former and therefore has half of its size. These young Amoebae, by feeding and manufacturing new protoplasm from the food-materials, in due time grow to their full size. It is perhaps not out of place here to insist on the fact that in this process all the constituent parts of the new cells restore themselves to their original condition in the old cell; in other words that, as the cytoplasm forms new cytoplasm, so the chromatin forms new chromatin of its particular composition, the linin new linin, and so on; the result being that, when the daughter-individuals have reached their full size and prepare for a new division, they resemble the mother-individual both qualitatively and quantitatively.

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* From φαίνω—see note †, p. 4; φάσις—appearance, specially means the various "appearances" which one and the same object may present during the course of certain regular changes; think, for instance, of the "phases" of the Moon.

Experiments have also been made in cutting Amoebae artificially into two; the results have been remarkable, inasmuch as they showed that the cut pieces became immobile and died after a few days, at the most, when they consisted solely of protoplasm, whereas, when they contained the nucleus, they lived on as before, growing to their full size and then dividing, just as ordinary individuals. We shall have an occasion to refer to these observations repeatedly in the sequel.

By its normal division into two (and all conditions being favourable) a single Amoeba may develop into thousands of individuals in the course of a few weeks. However, this process does not go on unlimitedly.

Even if we give the animals, in artificial cultures, every possible care, there will come a time when they begin to disappear in increasing numbers until in the end not a single individual will be discoverable. In the case of certain forms of Amoeba this result is due to the fact that the animals have practically all perished, or, as the technical expression is, that the culture has "**died out**". This phenomenon and its probable biological significance will be returned to on a later occasion (p. 158f). In the case of some forms of Amoeba, on the other hand, even a superficial search will show that the disappearance from the culture of the freely mobile individuals is accompanied by the appearance in it of a commensurate number of small spherical bodies with a sharply drawn, doubly outlined shell and a very pale content. Without giving particulars at present I limit myself to the statement that these bodies are in fact the lost Amoebae in another shape: they have contracted, have ridded themselves of all food-materials, and have surrounded themselves by the shell described.

The process here sketched as observable in certain forms of Amoeba is of frequent occurrence in other lower organisms; it is called "**Encystation**"* and has an interesting general biological significance. Many simply organised creatures live in water or, at least, moist media. The greater number of the accumulations of water on our earth, especially the smaller, are not "permanent" but dry out for a certain period of the year. It thus becomes of vital importance for all the small organisms which populate such water, to find some means of preserving their lives (and thereby their race), during these periods of dryness. In a former chapter (see p. 50) I mentioned certain forms which have acquired the capability of simply drying out with the water, and reviving with the return of moisture. However, this method of obviating the difficulty under consideration requires a considerable amount of resistive power on the part of the organisms, a power which many do not possess, probably because there is a simpler means of protecting themselves against the destructive influence of desiccation. This is the production of a hard and impermeable shell, within which they remain moist while everything outside is dry. This shell, or "**Cyst**", is first secreted in the shape of a sticky substance all round the body, but soon becomes hard under the influence of the surrounding medium. In some cases, the organisms enclosed in such cysts remain as they were and simply break forth from the cysts as soon as moisture returns. More frequently, the organisms, while in their cysts, undergo more or less complicated changes which practically lead to a multiplication of the individuals and thus represent a true reproduction. The changes themselves may vary in nature ; some special examples will be mentioned, and discussed in detail, in the chapters on *Gregarina* (p. 134f), *Plasmodium* (p. 143), and Autogamy (p. 151f).

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* From the Greek κύστη, or κύστις—originally the urinary bladder, but, generalised, every bladder or bag.

These are the features of the life of Amoeba which chiefly interest us here ; they are, to recapitulate them : the peculiar form of movement, the peculiar manner of incorporating food-particles, and the peculiar form of multiplication by division.

The latter does not go on without limits, but after a time comes to a stop owing to either the death of the individuals or their encystation.

It has been hinted on page 63 that the faculty of amoeboid movement is shared by the **white blood-corpuscles** of the higher animals, including Man. You know that the blood of these animals, in fact of all those which we call "Vertebrates" (because they possess an internal skeleton composed of "Vertebrae"), is red; I will state here that this red colour is not dissolved in the blood-fluid (the so-called "blood-serum"), but carried by small bodies (in most cases cells) called "red blood-corpuscles" or "erythrocytes"[*]. The red colour of the blood as a whole is thus due to the presence of these erythrocytes. Among them, but in smaller numbers, we find the "white blood-corpuscles" or "leucocytes"[†], capable of amoeboid movement (Fig. 8, *a*, *b*, Pl. I). In the "Invertebrate Animals", i.e. those which are destitute of an internal skeleton composed of vertebrae, the blood contains only white corpuscles and is therefore colourless; in some few cases, it may be red also but, then, the colour is dissolved in the serum, not tied to cellular elements. An example of this is, among others, supplied by the earthworm (see further on p. 472). Now, it is interesting to note that the leucocytes, wherever they occur, also show the two other peculiarities of Amoeba mentioned above; their habit of incorporating solid foreign bodies has even developed into a factor of apparently great importance for the whole organism.

It was first shown by experiment that minute particles of carmine or indigo injected into the body of certain invertebrate animals were taken up by the leucocytes; for they were later discovered in great numbers in these. The same happens in the blood of vertebrates and hence the leucocytes, from their habit of "devouring" foreign elements, have by some authors been given the special name "**Phagocytes**"[‡]. It has been found that in the blood, for instance, many erythrocytes become broken up in the course of time. Their fragments, instead of remaining in the blood and polluting it, as it were, are collected by the leucocytes and transported to the spleen where they are finally disposed of. In the case of larger foreign bodies which cannot be devoured by one leucocyte, several unite to do the work, that is, they creep round the foreign body in large numbers until their bodies form a continuous layer of leucocyte-protoplasm round it, trying to destroy it in this way.

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[*] Greek, from ἐρυθρός—red, and κύτος—see note †, p. 55

[†] Greek, from λευκός—white, and κύτος.

[‡] Greek, from φάγω—see note *, p. 29, and κύτος—see note †, p. 55. The term literally translated means "devouring-cells".

Still more important seems to be the part played by the leucocytes in certain diseases. You probably know that many of these latter are caused by "Bacteria" (for details about these see pp. 301ff). Under normal circumstances, i.e. if in full health and power, the organism is capable of destroying the Bacteria by the production of certain substances which, dissolved in the various fluids of the body, offer the Bacteria conditions under which they are unable to grow. If, on the other hand, the organism is not in full health, or, perhaps, if the Bacteria are very numerous from the beginning, they may be able to thrive; they then produce substances (products of their metabolism) which act as poisons upon the organism and may in the end kill it (compare further on p. 309). In all these cases the "phagocytes" are very active collecting the Bacteria, for the latter are frequently found by dozens in their bodies. Phagocytes thus laden with Bacteria are found in especially large numbers in the spleen, the liver and the bone-marrow; so it seems that the Bacteria are carried to these organs in order there to be definitively destroyed.

According to a number of observers, the phagocytes devour the Bacteria while still alive and thus protect the organism from their fatal influence. The disease itself is described as a "struggle" of the leucocytes against the Bacteria. According to other observers, it is the organism itself which produces the protective substances and, by distributing them in the various fluids, kills the Bacteria. The phagocytes, in this case, would only collect the dead bodies of the Bacteria, as they collect the fragments of dead erythrocytes, and by removing them act as a kind of "sanitary street-police". At any rate, you see that that elementary form of movement exhibited by such a simply organised creature as Amoeba is is retained even in the bodies of the highest organisms for special purposes. The most important of these obviously is the incorporation and subsequent removal of solid bodies which, by their presence and gradual accumulation in various parts of the body, would disturb the regular working of the whole organism.

When speaking of the changes of colour in the chameleon (see page 19), I said that movements of certain minute parts of the body were at the bottom even of these changes. The parts referred to are cells densely filled with minute coloured granules; we call such colours deposited in cells "pigments"* and the respective cells "**Pigment-Cells**" (Fig. 7, Pl. I). They lie just below the surface of the skin and their colour is thus able to shine through it. Their most remarkable property is that, on the one hand, they may send out a large number of processes usually dividing again into numerous finer branches (as seen in the figure), and that, on the other, they may contract to irregular round bodies which only show the tenth or twentieth part of the diameter of the extended cells. In the former state their colour of course spreads over much larger areas and thereby becomes much more apparent than it does in the contracted state. In the chameleon, we find two kinds of such pigment-cells, one with a blackish, the other with a yellowish pigment; they lie in two layers one above the other. As long as the animal is under normal conditions both kinds of cells are equally extended and the result is the uniform, sandy or dusty colour. But when it becomes irritated it can contract one kind of cells and thus allow the other colour to become more or less alone apparent. Therefore the movements of the pigment-cells are the cause of the colour-changes in the chameleon.

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* Latin; "pigmentum" (from "pingere"—to paint)—colour.

Before leaving Amoeba I will point out once more that, in nature, there exist a great number of different "species" of this form of animal. They all show the particular mobility of their protoplasm; this mobility is therefore a property common to the Amoebae and compels us, scientifically speaking, to consider them as a group of "natural relatives", the natural relationship being manifested by the common form of movement and all that is connected with it. We call this group a "Class" and combine the animals it is made to embrace under the common scientific denomination "**Rhizopoda**"[*]. Amoeba therefore is a "member of the Class Rhizopoda", and the latter is, according to what was said on page 60, a part of the "Phylum" Protozoa. Among the Rhizopoda, we have the numerous "species". The differences which distinguish them are of very different nature and of very different intensity. Without at present burdening you with many more names, I will only give a few examples as illustrations of the differences alluded to. In the above description of Amoeba I pointed out that the pseudopodia may vary in shape and number, inasmuch as they are sometimes rounded (Fig. 2, Pl. II), sometimes pointed at their extremities (Fig. 1); that there are sometimes one or two only (Fig. 2), sometimes a dozen and more (Fig. 1), etc. These differences, however—and this is the point of importance—do not indiscriminately occur in the specimens of a "species" but are each limited to—in the scientific language: "characteristic" or "distinctive of"—a particular species. Any species therefore which at any time forms only one or two blunt pseudopodia, as, e.g. that depicted in Figure 2, will show this peculiarity in all its individuals and all its descendants so long as these live under normal conditions. And if for some other species numerous long and pointed pseudopodia are distinctive as, e.g. for that drawn in Figure 1, it will form pseudopodia of this description, whenever it is moving under the conditions it is used to. When examining samples of the water contained in the various ditches and pools of this country you will come across at least four different species which are clearly distinguishable from one another by the form of their pseudopodia. Apart from this, however, these species are very similar to each other; in other words, the differences between them are not very intense in degree. You will at once understand what this means when I say that we know other species of Rhizopoda which differ from those just discussed very remarkably by the fact that they build themselves a kind of house, from which they send out their pseudopodia, or into which they withdraw as they choose. The material of which this house is built may be again of different form and composition. There are species which simply secrete from their body-surface a sticky substance by which minute grains of sand are glued together and thus form an envelope round the body. The shape of this envelope may vary; there are species where it is simple and has one opening only, and there are others where it is branched and has several openings; these openings, of course, are necessary for the animal to come out and send forth its pseudopodia. In another group of species, the house consists of a horny substance without any admixture of sand-granules and has a very regular shape (Fig. 9, Pl. II). You see, there are variations, and what is more, those variations are not each confined to a single species but may occur in several which again differ, among themselves, in such constant but comparatively inconspicuous details, as were described above in the form and number of the pseudopodia. If you duly consider this state of things you will find that each "variation", as compared with the others, forms a group or unit of its own, inasmuch as it has a character not present in the others. Such small groups of very similar organisms exist in very large number in the whole animal kingdom; we call them in scientific language "genera" (one is a **genus**). The few details given above thus allow us to conclude that, among the Rhizopoda, there is a "genus" the members of which have no house around their body; there is another genus the members of which have a house consisting of minute sand-grains glued together by a sticky secretion, and there is a genus the members of which have a horny shell. We recognise these genera, and many others besides.

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[*] Greek, from ῥίζα—root, and ποῦς—see note *, page 63; the word about means to say: animals the feet of which come like roots out of the body.

The sea is populated by an astonishing variety of species of Rhizopoda. They nearly all of them have a house which, however, is chiefly made up of silicious acid manufactured by the animals themselves, and shows such multiplicity in shape and structure combined with elegance of form, that it would be difficult for Man to invent something more graceful. The most remarkable thing about this silicious "skeleton" is that it does not envelop the body, but lies within it. With regard to this character (and several others) these marine Rhizopoda differ fundamentally from all the others of which we have spoken. Among themselves, they show quite a similar partition into groups as we found in the latter; but taken as a whole they form a community of their own; just as the other Rhizopoda, as compared with these marine forms, assume the aspect of a separate and independent community. In science, we recognise these large communities as groups of "natural relatives" and call them "Orders". The particular name of the Order to which the fresh-water Amoebae belong, is "**Amoebozoa**" *.

I will not at this place proceed any further with the present discussion as I consider it merely as a kind of preparation for something which I shall have to explain later. The chief points which I want you to remember are these: All unicellular animals form a "Type" or "Phylum" of the animal kingdom, which bears the name "Protozoa". Among the Protozoa, we have a number of "Classes"; one of them comprises all Protozoa capable of making amoeboid movements; the name of this Class is "Rhizopoda". Among the Rhizopoda, we have a number of "Orders"; one of these bearing the name "Amoebozoa" comprises all those forms which may be naked, or supplied with an external house of various materials, but have no internal silicious skeleton. Among the Orders, we distinguish more or less numerous smaller groups, the smallest of which are the "genera". These are composed of forms which are very similar to each other and differ only by comparatively insignificant details which, however, are fairly constant and appear in all the individuals of the respective forms. These forms are the "species".

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* From ἀμοιβός, see note §, p. 60, and ζῶον, see note †, same page.

We now turn to the examination of an other Protozoon which is a member of a new Class not hitherto mentioned. The genus to which the organism belongs has the name :

2.—VORTICELLA (Plate III).

I shall first shortly describe its chief peculiarities (see Fig. 1). The species of Vorticella live exclusively in water. The **cell** which represents the body has the shape of a bell, or a cup, which of course you must imagine solid, not hollow as the objects named are. The protoplasm is somewhat granular and thus chiefly consists of entoplasm, while the transparent ectoplasm only appears as a thin superficial layer with a very sharply drawn outer contour. The latter is apparently due to a somewhat more resistant modification of the ectoplasm, which covers the body after the fashion of a skin and is indeed considered as a kind of skin, called "**Pellicule**" *. On the anterior flattened aspect of the body we find a large number of fine, short hairs arranged in rows ; they bear the name "**Cilia**"†. I will here provisionally mention that the differential characters of these cilia are their shortness and their large number ; we shall see later that certain unicellular organisms have similar hair-like processes which, however, rarely exceed two or three in number and are much longer like the lash of a whip ; we distinguish them from the cilia by the separate name "Flagella"‡. In the protoplasm of Vorticella there is a well-developed **nucleus** of horseshoe-shape ; it lies with its long axis at right angles to the axis of the body (*N*, Fig. 1). At the posterior end, the latter is drawn out into a long, transparent filament, called the "**Stalk**" (*St*, Fig. 1), by which the animal is fixed to some solid object, either some particle of mud, or the body of some other organism (animal or plant) living in the water.

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* "Pellicula"—diminutive form of the Latin "pellis"—skin.

† "Cilium", Latin—hair; in particular the short hairs of the brows and lashes of the eye.

‡ "Flagellum", Latin—whip, scourge.

Our object is to study the manifestations of life observable in this Vorticella. What we have just learned of its structure suggests that they present certain differences from Amoeba. To begin with, Vorticella cannot make amoebic movements ; for the resistant pellicule which was entirely absent in the "naked" body of Amoeba prevents it from sending out pseudopodia and thereby continually changing its shape. Vorticella, as a matter of fact, has what we call a "definite shape", i.e. a shape which can be changed only within narrow limits and for comparatively short periods, after which it always returns to its original state. In Amoeba, the movements were of additional importance in the process of feeding. The incapability of making similar movements compels Vorticella to develop some other contrivance for providing its food. The particular structure of Vorticella, if duly considered, thus renders it certain from the outset that the differences from Amoeba will chiefly concern its form of movement and manner of feeding.

Movements. When we examine a living Vorticella under a low power, we observe that from time to time its **stalk** suddenly shortens and drags the body towards the point of fixation with almost the quickness of lightning. On close observation with a somewhat higher power, the stalk is then found lying in dense spiral turns similar to those of a cork-screw (lower part of

Fig. 1). They soon open again and the stalk slowly resumes its straight attitude, to be withdrawn in the same way sooner or later. This stalk is therefore "contractile" and, under a medium power, we also notice a certain structure in it. It is cylindrical and quite transparent, but throughout its length, a band of a slightly more refractive substance is seen running in long spiral lines (*St* in Fig. 1). I do not know whether you ever had an occasion to look through the barrel of a rifle; those of you who have will remember that it presents a peculiar appearance; several bands slightly raised above the general surface, and parallel to each other, running in long spiral lines round the axis of the cavity. The arrangement of the band in the stalk of Vorticella is similar; the only difference is that in the barrel of the rifle there are several such bands, while in Vorticella there is only one. The substance of this latter alone is contractile, and by its contraction produces the coiling of the stalk.

The formation of the spiral coils is a direct consequence of the spiral arrangement of the contractile band. Instead of a long theoretical explanation of the causal connection between the two facts, we will make the following experiment. We take a piece, about thirty centimetres long, of indiarubber-tubing, and a piece of string about twice as long. We gently wind the string in long spiral lines round the tube, leaving a part of string free at each end, and tie tube and string loosely together at the ends of the tube. The string now runs round the periphery of the tube as the contractile band runs round the stalk of Vorticella; it is irrelevant for our purpose that the band lies against the inner surface of the stalk, while the string lies outside the tube. Now let us take the free ends of the string and pull them apart; if the tube is soft enough we will succeed in stretching the string perfectly; but at the same time the tube assumes a spiral arrangement. If the string were capable of contracting still more, the coils of the tube would become denser than they actually are. If we cease pulling, the tube again becomes straight, but drags the string into spiral coils. Here you have a rough imitation of the connection which exists between the actions of the contractile band and the stalk in Vorticella: when the band contracts, it forces the stalk into spiral coils; when it relaxes its power, the stalk extends by its elasticity, but at the same time draws the band into a spiral course.

If you now remember that this band is only a part of the general body-protoplasm you will see that it is a part which has taken upon itself the special function of contraction, and has, in connection with this, assumed a special aspect and arrangement; you here have an instance which shows how the principle of division of labour is capable of working within the body even of a very simply structured organism. You ought to notice, further, the strand-like shape of the specialised part, for we already saw on page 36 that the form of a fibre seems just the one best adapted for bringing about a result by contracting.

The contractile band of the stalk is not the only structure of this sort present in Vorticella. The lowest part of the body which runs out into the stalk is in many forms separated from the rest by a more or less conspicuous constriction and thus appears as a kind of socle. It may be shortened independently, and the contraction is brought about, here again, by minute fibrillae which radiate out from the point of insertion of the stalk in a forward direction (*My*, Fig. 1). They are only discernible under high powers of the microscope and are then seen lying immediately under the pellicule in the ectoplasm, of which they apparently represent differentiated portions. Such minute fibrils are present in many Protozoa, and have been given the special name "**Myonemata**"*. In addition to those just described there is, in Vorticella, another set which run round the body in a transverse direction (indicated along the borders of the body in Fig. 1). They seem to bring about a third phenomenon of movement. We shall see presently that within the anterior aspect which carries the crown of cilia there is an area not covered by the pellicule; in other words, an area in which the body-protoplasm is "naked" as in Amoeba. Now if the water in which the animals live contains disagreeable or harmful substances, or be it for some other reason, the fact is that Vorticella is capable, usually with a concomitant withdrawal of the stalk, of folding its whole anterior surface with the cilia inwards to such an extent that the anterior margin of the pellicule closes on the top, the body assuming thereby an almost spherical shape now covered all round by the pellicule. This contraction seems to be brought about by the circular myonemata, above described, and more in particular by those lying near the anterior margin of the body; it naturally leads to a passive distension of the remaining myonemata lying farther backwards, whereas these, when contracting in their turn, would restore the original conditions, i.e. again unfold the cilia. Practically, this usually takes place after the stalk has again been uncoiled. Owing to this habit it is very difficult, and requires a circumstantial procedure, to preserve Vorticellae with their cilia unfolded; for the most part the specimens, at the moment of preservation, contract and then appear as round or ovoid bodies without any trace of cilia at their anterior ends; also the stalk is tightly coiled up (compare here p. 90, about the irritability of Vorticella).

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* Greek, from μῦς (genit. μυός)—mouse and muscle, and νῆμα—thread, fibre.

The movements we have thus far spoken of were movements of contraction, i.e. changes of shape, and were brought about by fibrillar differentiations within the protoplasm. But Vorticella exhibits still another totally different form of movement which is generally known under the name "**Ciliary Movement**"; it is brought about by the cilia adhering to the surface of the body, and its result is "locomotion", i.e. a **change of place.** Before proceeding further I must describe the "**Ciliary Apparatus**" of Vorticella somewhat more in detail. It occupies, as already stated, the anterior aspect of the body but presents an arrangement which is difficult to describe, and also varies somewhat in the different species. Quite generally speaking, it may be said that the anterior surface, although almost flat if taken as a whole, yet has a furrow dug into it which, starting from some point of the margin, runs along it for some distance and, while doing so, gradually draws somewhat nearer to the centre. At first rather shallow, it gains in depth as it runs on and terminates in a kind of funnel (*Cph*, Fig. 1) which extends fairly deep into the entoplasm and is—in its lower part at least—no longer lined by the pellicule. Both the whole free edge of the body proper and the inward free edge of this furrow are beset with a continuous row of those fine, hair-like protoplasmic processes which we mentioned as cilia; they (or similar structures) also extend for a certain distance into the funnel but do not reach its bottom. The whole structure here described, with the exception of the funnel, is called the "**Peristome**"*.

The cilia, during life, are in constant, uniform, to and fro movements; these are usually so rapid that they cannot be distinctly followed, but slow down considerably when death approaches, and become then more easily observable. In order to explain the signifiance of this ciliary or “ vibrating ” movement, and the effect produced by it, I will again use an example from our daily life. You all know the common rowing boats ; there are such which are moved by one man with two oars only, and there are others, especially used for racing, which are moved by half a dozen or more men ; the men, while at work, all move their oars in unison. If you imagine a boat of the latter kind firmly anchored the men, by using their oars, would produce a backward stream in the water all along the boat; if this becomes loosened, there will not only be a backward stream in the water but,in addition, a forward movement of the boat. I think these facts and their physical reasons are familiar to you ; they give you the explanation of the various effects which may be produced by the movement of the cilia, each of which, in form and action, to a certain degree represents an oar. If the cilia adhere to a free cell, they produce a locomotion, i.e. a change of place, of this cell. If they adhere to a fixed cell, they produce a locomotion of the medium, i.e. a stream in the fluid which bathes the surface to which they adhere. This difference can easily be demonstrated.

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* Greek, from περί—round about, and στόμα—mouth; therefore a structure "surrounding the mouth".

Cilia are very common in the animal organism, and are—a very suggestive fact—chiefly met with in connection with epithelial tissue which is then called “ vibrating epithelium ”. It covers, for instance, the inner surface of the trachea of Man and animals. If you clean the trachea of a newly killed animal from the adhering mucus, scrape off a part of the epithelium, and examine it in some fluid which does not kill the cells, you may see the uniform movement of the cilia over whole areas of the membrane. Small granules contained in the fluid, if they come in the neighbourhood of the cilia, are quickly carried away in the stream produced by them. However, if you look for a cell, or a small group of cells, detached from the others, you will find that these swim about in the fluid with irregular whirling movements as if they were independent living creatures. Here you see the different effect of the ciliary movement on one and the same object and in one and the same preparation.

In Vorticella, the cilia stand on the edges of the body and of a furrow which leads from the free margin into the funnel-shaped depression; the whole animal is anchored to the ground. The effect produced by the ciliary movement must here be a general stream in the water going towards the animal and a special stream branching off from the general along the row of cilia and ending in the funnel. If, on the other hand, Vorticella is loosened from its support, the cilia turn into actual organs of locomotion. It not unfrequently happens that, while making a preparation, one accidentally detaches a Vorticella from its support. Such specimens are then seen swimming with great agility through the water, dragging their fully stretched stalks after them (see also p. 91).

Recapitulating now what we have learned about the movements of Vorticella we see that they are no longer general, i.e. spread over the whole body (as was the case in Amoeba), but "localised"; the bulk of the body has lost the capability of moving, while certain parts have retained it in a special degree. There are, on the one hand, the myonemata capable of contracting and changing the shape of the body, and there are, on the other, the cilia comparable to oars, which produce a movement from the spot, either of the organism or of the medium surrounding it. Myonemata and cilia are products of a division of the labour of the cell, and in their particular shape show functional adaptation.

Returning now to the cilia and the movement they were said above to bring about in the case of a fixed Vorticella we can easily convince ourselves of the phenomenon by adding a thin emulsion of carmine or indigo colour to the water in which we have some specimens under the microscope. The colours named consist of very minute granules, light enough to be moved about by the power of the cilia. So we see that (compare Fig. 1, Pl. IV) they soon begin to whirl towards the anterior aspect of the Vorticella, some hitting against this, others passing by it on either side. While the latter are gradually drawn forward again in a wide outward circle, the former are caught by the cilia which guard the furrow and are by these transported to the funnel where some are kept back while a smaller or larger number again escape and leave in a direction opposite to that from which they came; the respective directions are indicated in the figure by arrows. The most interesting feature, however, is that the colour-particles which remain at the bottom of the funnel, and there slowly accumulate, are after some time seen to form small round balls within the body. These balls first lie near the bottom of the funnel, but subsequently shift away from it and towards the anterior surface, near which they gradually approach the funnel again, until, at a given moment, they suddenly disappear, while the granules they enclosed pass over into the funnel and become mixed with those which leave at once, i.e. without making the circuit through the body.

The singular phenomenon here described affords the explanation for the process of **feeding** in Vorticella. The mouth lies near, or at, the bottom of the funnel-shaped depression in the anterior surface (*Cph*, in Fig. 1, Pl. III). It is not an actual opening as in the higher animals, but simply a "naked" part of the body-protoplasm, i.e. a part not covered by the pellicule, and accordingly capable of incorporating solid particles after the fashion of all the body-protoplasm in Amoeba. The food of Vorticella, like that of Amoeba, consists of minute organisms, or fragments of such, which under natural conditions are caught in the whirl produced by the cilia, just as were the colour-grains in the experiment above described. Under a somewhat higher enlargement it is also possible to see how they are incorporated. The end of the funnel, at first simply pointed, becomes somewhat dilated while food-particles are received in the dilation. Their number slowly increases by new arrivals and the dilation widens accordingly (*fV**, Fig. 1) until at a given moment it becomes detached from the funnel in a similar manner as, e.g. a drop of fluid becomes detached from the point of a pipette; in the drawing it is seen very near to that moment. While the bottom of the funnel then reassumes its original shape the dilation, with the food-materials it encloses, rounds itself off and now represents what from the description of Amoeba we know as a **food-vacuole**. In Vorticella, five and six such vacuoles are not infrequently found side by side (*fV* in Fig. 1), slowly shifting their position as above described while their contents are being digested. The process of removal of the indigestible remains is again directly influenced by the presence of the pellicule, inasmuch as it cannot take place except at a spot unprovided with the latter. Such a spot is usually found near or at the entrance of the funnel; the food-vacuoles, after having made their circuit in the body, approach it until the protoplasm which separates them from the body-surface ruptures and thus allows the contents to escape as we saw above.

If we now review the whole process of feeding in Vorticella it is not difficult to see that, in essence, it is the same as in Amoeba; the only difference being that mouth and anus are localised owing to the presence of the pellicule, while the **cilia play the part of auxiliary or subsidiary*** **organs for feeding.**

Excreting. The process of excreting, in Vorticella, is the same as in Amoeba, and need not therefore be described again. It is, in Vorticella, easily observable, as the contractile vacuole (*cV*, Fig. 1, Pl. III) is usually fairly large and not obscured by granules. It lies near the anterior surface and near the funnel, and always appears at the same place, so that it seems to be a permanent structure which only disappears from view temporarily, owing to its want of contents. If this is true we here have another instance of the working of the principle of division of labour. A special part of the body-protoplasm is " delegated ", as it were, to look after the removal of the waste-products and, in connection with this task, has assumed particular faculties. One of these is the obvious contractility of the wall, which enables the vacuole to actively empty its contents.

Respiration, in Vorticella, is as little observable by outward signs as it was in Amoeba. In explanation of this circumstance you must remember, first, that the gases concerned in the process, viz. oxygen and carbon-dioxyde, are invisible; second, that in Amoeba and Vorticella there are as yet no special parts of the body delegated for respiration. The function is apparently performed in the entoplasm; in order to reach this the oxygen, dissolved in the surrounding water (see above, p. 6), has to pass through the ectoplasm, and so does the carbon-dioxyde produced by the respiration when it leaves the body. We find similar conditions in a large number of lower animals, and quite especially amongst such as live in water. They have no special respiratory organs, or, in other words, the general body-surface is their respiratory organ, inasmuch as it allows the passage of the gases concerned in the process.

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* From the Latin "auxilium" and "subsidium", meaning both help, aiding.

What has just been said of respiration applies to a large extent also to **irritability**. The phenomena of movement described above give ample evidence that Vorticella is irritable. But there is as yet no specialisation; the body does not contain any structure particularly devoted to the function. This is still " generalised", as we might say, inasmuch as every part of the ectoplasm is equally fit to receive outward stimuli and to make the whole body react upon them.

Reproduction again offers certain features of interest. To begin with, there is a reproduction by **division** as in Amoeba. The principle of the process is the same as there described ; however, as the shape of the body is definite in Vorticella the division of the individual also takes place in a definite direction. It is, in Vorticella, longitudinal and proceeds from before backwards. Thus, after the division of the nucleus, the various parts of the peristome become first doubled and then separated from one another by a cleft which gradually grows deeper and finally reaches the point where the stalk is inserted. At this phase, we therefore have two small Vorticellae carried by a single stalk (see Fig. 2, Pl. III). What happens subsequently is different in the various groups of natural relatives which exist among the Vorticella-like Protozoa just as they exist among the Amoeba-like (see p. 75ff). In a number of genera, one of the two individuals adhering to the stalk develops a "posterior crown of cilia" along the constriction above described (p. 82) which separates the socle-like lower part from the rest of the body (see the individual to the right in Fig. 2) and, after that, severs its connection with the stalk. As soon as it is free the cilia turn into locomotory organs (as I tried to explain on p. 86) and the organism swims about in the water with great agility. After some time of such free life, it settles again on some solid object, attaching itself to it with its posterior end which slowly grows out into a new stalk, while the posterior crown of cilia, now no longer necessary as a locomotory organ, is withdrawn. By feeding and building up new body-protoplasm it gradually grows again to the full size, as does the other half which remained on the original stalk. In this way, new Vorticellae continually arise, e.g. in a basin with water which originally contained only a few. However, this multiplying power, in Vorticella, is as limited as it was in Amoeba. Sooner or later the individuals in the basin begin to show signs of degeneration; they do not divide any more and in the end entirely disappear from the culture (compare p. 70).

In other genera of Vorticellae, the splitting up of the body goes on as described but is continued over a more or less long portion of the stalk. The two new individuals do not become detached from it, as, indeed, neither produces a posterior crown of cilia, and so we have, at the end of the process, two Vorticellae each attached to the end of a forked stalk (Fig. 3*a*). They in due time grow to their full size and then, division should take place again. It does so in fact, and the result is that, now, we have four Vorticellae on the tips of a doubly forked stalk (Fig. 3*b*).

A new division would lead to the formation of eight individuals (Fig. 3*c*), and so you see that, in these forms of Vorticella, the reproduction of the original organism does not lead to the formation of numerous isolated specimens distributed here and there in the water, but to the formation of a tree-like community of individuals at the place occupied by the first individual. Such communities, arising from the division of one original individual, are fairly common among the lower animals and plants, and are generally called "**Colonies**" (see e.g. also *Spirogyra*, p. 241 : *Hydra*, p. 418). The condition necessary for their formation is that the division of the individuals be "incomplete", i.e. do not lead to a perfect separation of the products of each division. The individuals of a colony are, among themselves, alike; each cares for itself and indeed, would be able to live on independently if accidentally separated from its associates.

Occasionally, Vorticella seems to multiply by another form of reproduction which may be considered as a variety of the reproduction by division, and is called reproduction by "**Budding**". According to what we have thus far seen of the former the two new individuals are from the first about equal to each other in size ; this is no longer the case in the form of reproduction just alluded to. It begins, like the ordinary form, with a division of the nucleus ; this, however, usually assumes the aspect of the cutting off of a small part from the bulk of the nucleus, rather than the aspect of a true division. This small part shifts towards the surface of the body and, in so doing, pushes a certain amount of the protoplasm in front of it until this causes a distinct bulging of the surface. The bulging still increases in size to some extent and,. after the entrance of the detached part of the nucleus into it and the formation of a new peristome at its free end (compare here p. 422), becomes perfectly separated from the body to grow in due time into a new Vorticella. We call this mode of reproduction "budding", because of the resemblance the first stages of the young individuals bear to the buds in plants. Its difference from ordinary division lies chiefly in the fact that one product of the division, when it first arises, differs from the other more or less considerably in size.

This reproduction by budding is widely spread, especially among the lower organisms (see e.g. the yeast, p. 298; *Hydra*, p. 417). Among the Protozoa, it occurs in various forms of Vorticella but is particularly characteristic of some of their more distant relatives which are also fixed to the ground by a stalk, but have no cilia (see Fig. 5, Pl. IV). In their place, these forms possess a number of immobile, cylindrical, protoplasmic processes, each with a small knob at its end, which seems to secrete a sticky substance. Small vagrant organisms, if they touch one of these knobs, are retained by it, and their fluid content is thence sucked out by the animal. From this structure and manner of feeding the Protozoa in question have received the scientific name "**Acineta**" or "**Suctoria**"*. One of the respective species (*Podophrya gemmipara*; Fig. 6, Pl. IV) is characterised by a ramified nucleus; when a period of multiplication approaches we see that the knobbed processes are withdrawn, while at the same time a number of buds grow out from the anterior surface, each pushed, as it were, by a prolongation of a nuclear branch. Subsequently, the terminal portions of these branches sever their connection with the main nucleus (the preparatory constrictions are visible in the drawing) and their example is followed by the buds which in the meantime have developed cilia on their outer surface. In this shape they swim about in the water for some time; then, however, the cilia are gradually withdrawn and knobbed processes appear in their place (Fig. 7); in the end the former buds settle again and by forming a stalk assume the shape of the normal individuals.

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* *Acineta*, from the Latin "acinus"—berry (referring to the swellings at the ends of the processes); *Suctoria*, from the Latin "sugere"—to suck.

When the multiplication of Vorticella by division has gone on for some time and numerous descendants have arisen from the original, the process may undergo a remarkable change. We then see that certain specimens divide as before but, without allowing themselves time to grow, at once divide again and perhaps, may even do so for a third time. It is self-evident that under these conditions the products of the division must become smaller with every division (see Fig. 4, Pl. III). They soon all acquire the posterior crown of cilia mentioned above (p. 91) and finally all loosen their connection with the stalk. The further fate of these small individuals is equally remarkable. Instead of settling, after a period of free movement, on some solid object, they choose for their place of rest one of the larger undivided specimens of their own race (Fig. 5, Pl. III), attaching themselves to them, coalescing with them, and being, in the end, completely taken up into their bodies. The larger specimens, after this fusion, go on dividing more energetically than previously. Before you can fully understand the biological significance of this interesting process you must be made acquainted with a number of other details of the life of the cell. So I will defer all further explanations until a future occasion (see pp. 131ff).

Before passing on to a new subject it will be well to recapitulate what we have learned from the observation of Vorticella. Structurally, the body is no longer so uniform as it was in Amoeba, but presents a number of specialised parts (stalk, myonemata, cilia, pellicule), the formation of which is due, biologically, to a division of the labour the organism has to do in order to maintain its life. The specialisation in the first place concerns the ectoplasm which is in direct contact with the outer world and thus naturally has, as it were, to mediate between it and the organism. So we see that it supplies the means for moving about and for procuring the food; two purposes, by the way, so intimately connected with one another that it is often practically impossible to sharply separate them. The ectoplasm, further, has to protect the body against any harmful influences in its surrounding medium, and for this purpose has to develop a resistant surface; but it must at the same time allow the passage of gases through it (for the purpose of respiration) and must be sensitive to outward stimuli. The two latter functions are not yet specialised, i.e. the ectoplasm has not yet formed any special structures particularly devoted to them. At variance from the ectoplasm, the entoplasm is concerned, we might say, in the "household-work" of the organism: it has to look after digestion, respiration, and secretion but, apart from that, shows no particular differentiation.

3.—CILIATA.

At the end of a former chapter (p. 79) I gave you to understand that the various forms of Vorticella are members of a Class of Protozoa not up to that time mentioned. This Class has received the name "**Ciliata**" — a name which in one word points out the character which distinguishes the forms belonging to it. When you think of the Rhizopoda you will remember that they had pseudopodia as organs for movement and feeding; the Ciliata, for the same purpose, have Cilia. I may mention here that another very old name of the Ciliata is "**Infusoria**"; it refers to the fact that these organisms usually develop in large numbers in "infuses", i.e. mixtures of water with certain dried herbs made in order to get extracts of the latter. The Ciliata, or Infusoria, then, are a second Class of the Protozoa.

Vorticella, as already stated, is a member of this Class; a member, however, which differs from all its other relatives by the fact that it is fixed to the spot by a stalk. The other Ciliata do not possess a similar structure and are, therefore, freely mobile. They exist, in nature, in hundreds of species, all different from one another. You may imagine that for the aims of science it is necessary to obtain a clear survey of all these various forms and to sharply distinguish every one of them from its congeners. We do that by establishing what we call a "**Scientific Classification**" in which every species receives its definite place. In order to make you see the advantage and practical necessity of such a classification, I may quote for comparison a public library, or some big warehouse. If in either of these the various articles were indiscriminately thrown, one beside or on to the other, you will have no difficulty in seeing that a survey of what was present would be as impossible as it would be to quickly find one particular article that was required. The scientific classification of the organisms is to obviate similar inconveniences in the various branches of Biology. The principle which guides us in establishing this classification, i.e. in determining the place which must be assigned to any particular creature, is the principle of the "natural relationship". This, in its turn, is determined by the greater or lesser similarity in structure and life-history exhibited by the various organisms, in such a way that organisms which closely resemble each other in structure and habits are also considered as close "natural relatives", whereas the relationship becomes the more distant the more certain organisms differ in structure and development. I have already tried to show you the practical application of the principle of classification in connection with the Rhizopoda (see p. 75ff). I will here complete the picture by saying a few words about the classification of the Ciliata.

As, among the Rhizopoda, we were able to distinguish a number of "Orders" so also among the Ciliata. While the shape of their body varies to an extraordinary degree, the ciliar covering varies also, but shows certain types which are fairly sharply marked off from one another ; so we use these latter differences for defining several Orders within the Ciliata. There is first an Order, in which the cilia are all about equal in size, and are also equally distributed all over the surface of the body; we call this order, from the character here given, "**Holotricha**"*. A member of it, among others, is the genus *Opalina*, the representatives of which live, often in large numbers, in the large intestine of frogs and toads (Fig. 2, Pl. IV). They are remarkable for the complete absence of any distinct mouth. This feature which may seem striking at first becomes comprehensible if we consider the conditions under which the Opalinae are living. The large intestine we know collects the indigestible constituents of the food before their evacuation ; but, in addition to them, there are probably always remains of the liquefied true food which

* Greek, from ὅλος—whole, entire, and θρίξ (genit. τριχός)—hair the whole body being covered with cilia.

have not been absorbed during their passage through the small intestine. This fluid nutritive material prepared as it was for absorption is fed on by the Opalinae ; it is capable of being absorbed into their bodies as it would have been capable of being absorbed into the body of the frog. In the latter case it would have passed through the cells lining the intestine without requiring particular openings to do so ; in the same way, it may pass through the body-wall of the Opalinae and thus make a separate mouth-opening unnecessary. A further peculiarity of *Opalina* is the presence within the body of numerous small round nuclei of equal aspect (*N*, Fig. 2, Pl. IV).

A more typical representative of the order Holotricha is the genus *Paramaecium* (Fig. 6, Pl. III). Its members live in stagnant water and have a distinct mouth-opening which lies on the ventral side and nearer to the posterior than to the anterior end (*Cst*, Fig. 6). A furrow similar to that described in Vorticella leads to it from before backwards, and also ends in a funnel-shaped depression, at the bottom of which the actual incorporation of the solid food-particles is effected (note the small food-vacuole just being formed at the inner end of *Cph*. Fig. 6). A continuous row of cilia, slightly larger than those of the body proper, extends along the free edge of the furrow and down to about half the depth of the funnel. At variance from the cilia of the body, which are organs of locomotion, these latter cilia are "auxiliary" organs for feeding, for they have the particular task of leading suitable food-material to the mouth, as described in Vorticella. Whereas, in this latter, the indigestible remains of the food were emptied into the funnel, and thus left the body by the same way as that by which they had come, *Paramaecium* (as many other Ciliata) has a separate opening in the pellicule for the removal of the faeces, an opening which, functionally, therefore represents an anus. Instead of one contractile vacuole, as is usual, *Paramaecium* possesses two, situated near the anterior and posterior ends of the body (*cV1* and *cV2*, Fig. 6). They contract in the main alternately, evidently in order to allow the process of excretion to go on without interruption. Still more interesting are several structures observable in connection with them. Thus, a very minute pore has been discovered, immediately above each vacuole, in the pellicule, and an equally minute duct has several times been seen which connects the pore with the vacuole. In the entoplasm surrounding the latter there appear, at about the time of each contraction, fine clefts, six to eight in number, which start from the vacuole in a radial direction and become lost in the entoplasm after a short course (*ccV*). Their behaviour during the pulsation of the vacuole leaves no room for doubt that they are ducts collecting the excreted fluid from the entoplasm and leading it to the vacuoles. In *Paramaecium*, we finally find the two different nuclei, to the existence of which allusion was already made on page 56f. There is a fairly large and conspicuous "**Macronucleus**" and a very small, intensely staining "**Micronucleus**"* which usually lies close to the wall of the Macronucleus and is not always easily discernible (*Ma* and *Mi* in Fig. 6). The very different significance these two nuclei have in the life of the animal will be discussed in connection with the modes of reproduction of *Paramaecium* (cf. p. 130).

Another Order of the Ciliata in general resembles the Holotricha but differs from them by the fact that the furrow leading to the mouth is developed into a distinct groove of varying shape, the free edge of which is adorned with cilia noticeably longer than the rest and, in addition to them, by so called "undulating membranes", i.e. very delicate membranous expansions of the ectoplasm which during life are in a constant wavy movement, the effect of which is the same as that of the movement of the cilia. As a matter of fact such undulating membranes, in many Protozoa, either replace the cilia (or flagella), or else are found in addition to them. From the difference in the size of the cilia the Order here spoken of has received the name "**Heterotricha**"[*]. A well-known member of it is the genus *Balantidium*, a species of which sometimes inhabits the intestine of Man (Fig. 3, Pl. IV).

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* From μακρός—see note †, p. 50, and μικρός—see note *, p. 33.

In a further Order of the Ciliata called **Hypotricha**[†] the diversity in the size and the distribution of the cilia is still more marked. We then have a dorsal aspect in the main entirely free from cilia (whence the name of the Order) and a ventral aspect on which the cilia are considerably reduced in number but have, instead, developed into stout, bristle-like structures of various shape and arrangement, distinguished under the separate name "Cirri"[‡]. By their help the animals may row about in the water but are also capable of running, or climbing, about on other solid objects (animals or plants), living in the water, as if the cirri were true feet. A well-known member of these Hypotricha is the genus *Stylonychia*, the species of which usually make their appearence in large numbers in foul water. Such a *Stylonychia* is represented in Fig. 4 of Plate IV; it is remarkable by the presence of two Macronuclei and two Micronuclei. In the specimen depicted the

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[*] Greek, from ἕτερος—see note *, p. 53, and θρίξ—see note *, p. 97.

[†] Greek, from ὑπό—under, below, and θρίξ—see above.

[‡] "Cirrus", Latin, originally—curl, or fringe; scientifically usually employed in the sense of "bristle".

(rod-shaped) body of a devoured Alga is just being evacuated from the anal opening *Cp*.

The Order to which Vorticella belongs is called **Peritricha** * as indeed cilia are here present only " round " the peristome. We saw on page 89 that these cilia are auxiliary organs for feeding, whereas the others covering the general surface of the body, wherever they are developed, are organs of locomotion. You will see without difficulty that the former are necessary for Vorticella, for it must feed; but that the latter would be superfluous, as Vorticella is fixed to the spot by its stalk. The interpretation here given of the absence of locomotory cilia in Vorticella is further borne out by the fact that such cilia temporarily develop (in the shape of the posterior crown, see p. 91) in the vagrant stages, but become lost again as soon as these stages settle down to a sedentary life. You here have a practical instance of a phenomenon observable throughout the world of organisms, namely, that the structure of any creature is " dictated ", as it were, by its particular habits or, in other words, that **any organism, in its external equipment, appears to be "adapted" to its manner of life.** It is, by the way, a result of this same adaptation, that the human arm, the foreleg of a horse, and the wing of a bird, mentioned on a previous occasion (p. 35), though being homologous, i.e. identical organs, yet exhibit so different a shape.

If we now review what we have learned about the organisation of the Ciliata there is one point of particular general interest, and this is that these animals in their bodies possess parts functionally absolutely corresponding to those which, in a previous chapter (p. 30f), we

* From περί—see note *, p. 84, and θρίξ—see note *, p. 97.

characterised as "organs" and which, in the preceding description we now and then already called organs. They are indeed **organs**, but the remarkable thing about them is that they are not composed of tissues and cells, but are mere specialised parts of one and the same cell; a cell, however, which leads an independent life as an independent organism. As such, it must perform the various functions of life, and we thus see that, even within the narrow limits of a cell, the organism tries to specialise its labour by quasi "delegating" individual parts for the various individual functions, and that these parts, in their particular shape, externally exhibit the attributes of their functions. We on a previous occasion spoke of a "small household" in which the master of the house does all the work alone (p. 25); here you have an instance that the simplest organism we know, viz. the cell, all by itself accomplishes the same work for which the higher organism requires millions of very different cells. These many cells, naturally, are enabled to do a much more specialised and, therefore, much more perfect work than the mere cellular parts of the unicellular organism are capable of. Functionally, however, these parts are organs just as well as those of the complicated higher organism; for practical reasons, it has been found necessary to distinguish them from the latter by a special designation, and so they have been termed "**organula**"*. Several of them have, in addition, received names of their own; thus, the mouth is called **Cytostome**† (*Cst* in Figs. 6,7, Pl. III; 3,4, Pl. IV), the funnel which leads from it to the entoplasm and functionally corresponds to the oesophagus is called **Cytopharynx** * (*Cph* in Figs, 1,6,7, Pl. III); the anus of the cell is the **Cytopyge** † (*Cp* in Figs 3, 4, Pl. IV). The name Myonemata for the contractile fibrils of the cell has already been explained.

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* Diminutive form of "organ"—therefore: "little organs".

† Greek, from κύτος—see note †, p. 55. and στόμα—see note *, p. 84.

If you finally compare the Ciliata with the Rhizopoda you will notice that, in the former, the process of the division of labour has advanced much farther than in the latter. In Amoeba, there is only a differentiation between the entoplasm which has to do the "household-work", and the ectoplasm which "mediates" between the organism and the surrounding medium, but does it in such a general way that any part of it is functionally equal to the rest. In the Ciliata, the ectoplasm in particular has developed a number of organula for special purposes; the Ciliata, in scientific language, are "more highly differentiated" than the Rhizopoda.

When speaking of Amoeba I mentioned certain interesting experiments in cutting specimens in two (p. 69). Similar attempts have also been made with various species of the above Ciliata, especially such as presented less technical difficulties on account of their larger size, and could be divided into more than two portions. The results obtained were exactly as in Amoeba. While all pieces consisting of protoplasm alone invariably perished, the others, even if they had retained a mere fragment of the nucleus, not only continued to live, but during their subsequent growth even "regenerated", i.e. produced again, all those parts, such as Cytostome, Cytopharynx, and Cytopyge, which had been removed by the cutting.

We must now turn to a number of phenomena connected with the multiplication of the cell.

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* As preceding terms, from κύτος and φάρυγξ—gullet.

† From κύτος and πυγή—anus.

CHAPTER V.

On the Various Forms of Division of Nucleus and Cell.

You have, in the preceding discussions, heard a good deal of the various shapes the cellular body may assume, and the various structures it may develop, in the different kinds of Protozoa. This multiplicity in shape and equipment is quite comprehensible, for the cellular body is in direct contact with the outer world and has, so to speak, to play the part of the mediator between the organism and its surroundings; but, nevertheless, you may perhaps have been struck by the fact that in the same discussions we had so little to say about the nucleus. It is true that this also varies somewhat in shape in the various forms, but these variations are nothing as compared with those of the body. We know, on the other hand, that the nucleus is present in every cell, and therefore, evidently, is an essential part of it. Since, however, it can be but little, if at all concerned in the intercourse between the cell and the outer world, the only possibility that remains is that the range of its activity must lie within the cell. That this conclusion is correct with regard to one point is evinced by the experiments in artificial cutting above related (pp. 69, 103), for they leave no possible doubt that it is the nucleus which instigates the vital capacities of the protoplasm, releasing, as it were, the forces it is endowed with. A second, equally important function of the nucleus will become apparent in our subsequent discussions; thus, on account of all the facts hitherto ascertained we see in **the nucleus that part of the cell which directs and regulates its vital activity in general, and specially determines the phenomena** of **reproduction and heredity.** The correctness of this view will be borne out by the facts described in the following chapters.

In the earlier epochs of biological science observers found no objection to admitting a wide distribution of what we technically call "**Generatio Aequivoca**" or "**Spontanea**"; i.e. it was a common belief that various organisms could, and did, arise "by themselves", from, and within, foreign substances. Thus it was assumed that eels and other fish arose from the mud at the bottom of the waters; that the maggots appearing in foul meat were produced by the process of putrefaction; that the various worms found in the bodies of Man and animals were derived from the organs and tissues of their bearers as the result of morbid processes. Owing to the application of more reliable methods of observation, all these earlier views were by and by recognised as errors; it was found that eels possessed genital organs as the higher Vertebrates, and that the young were derived from the eggs of the old; that maggots never appeared in foul meat unless flies had had access to, and had deposed their eggs on it; that the intestinal worms, even those living in organs entirely shut off from the outer world (as e.g. the brain), all originated from germs which entered the body while they still were extremely small. The last apparent proof of the actual existence of a spontaneous generation was found in the "Micro-organisms" (e.g. Bacteria) which appear in countless multitudes wherever a process of organic decomposition is going on. However, even this last stronghold of the defenders of the spontaneous generation has been destroyed by the irrefutable proof that no Bacteria ever develop in substances which are safely protected from communication, direct or indirect, with the surrounding medium (see also p. 306). So we have at present no evidence that any living creature can possibly arise without the help of preexisting individuals of its own race; not even a cell, or the nucleus of a cell, can arise independently; they all owe their origin to preexisting cells and nuclei, by the division of which they have been formed. These results of long years of careful and patient research have been "condensed", so to speak, into the three fundamental sentences: "Omne vivum ex ovo; omnis cellula e cellula; omnis nucleus e nucleo", which means: **Every living organism comes from an ovum, every cell comes from a cell, every nucleus from a nucleus.**

The division of nucleus and cell is thus a very important biological process. When speaking of the reproduction of Amoeba we saw that it is initiated by the nucleus; I may here state that this is the rule in every cell-multiplication; but apart from this, certain interesting variations may occur, which concern the division of the nucleus as well as that of the cell. For convenience' sake, we will here consider the two processes together so far as this is possible.

1.—THE "DIRECT" OR "AMITOTIC" DIVISION OF THE NUCLEUS.

The details of the process were described in connection with the reproduction of Amoeba (see p. 68). The distinctive character of this form of division lies in the fact that the nucleus, simply and without any apparent internal changes, becomes broken up into the two halves which represent the new or "daughter"-nuclei. This division is therefore indeed "**direct**" ("**amitotic**", according to the note * on page 4, is "non-mitotic"*); it is most easy to demonstrate in the leucocytes of Vertebrates, but also occurs in the nuclei of many Protozoa (e.g. *Amoeba*, Figs. 3, 4, Pl. II; *Paramaecium*, Fig. 7, Pl. III), and in certain tissues of higher animals and plants; it is perhaps peculiar to the nuclei of "senescent" cells *.

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* See note *, p. 107.

On page 92 we described the multiplication of cells by "budding" as a variety of the ordinary division into two. In most cases of such budding the nuclei of the respective cells also divide by "**budding**", that is, the products of their division, instead of being about equal, are at first more or less unequal. We already know examples of this variety of the nuclear division from Vorticella (see p. 92) and the Acineta (p. 93). It should, however, be pointed out that a budding of the cell is not always combined with a budding of the nucleus; we shall see presently, for instance, that at a certain stage the egg-cell produces two or three "buds", but that, in this case, the parts of the nuclei which enter the buds are equal to those which remain with the bulk of the cell (for details see p. 116).

2.—THE "INDIRECT", "MITOTIC" OR "KARYOKINETIC" DIVISION OF THE NUCLEUS.

(See Pl. V.)

This mode of division is by far more frequent throughout the world of organisms than the former, and is characterised by a series of very remarkable changes in the substances composing the nucleus. The entire series of these changes is technically called the process of "**Mitosis**" or "**Karyokinesis**" †, while the division is "mitotic" or "karyokinetic"; the name "indirect" will be comprehensible without further explanation. In order to distinguish the nucleus in the various phases of division from the nucleus in the shape it usually shows, the latter is called the "resting nucleus". The whole process of the karyokinetic division is often divided into three phases which respectively comprise (1) the "preparation" for the division, (2) the division itself, technically called the "Metakinesis", and (3) the "reconstruction" of the daughter-nuclei. For the sake of greater clearness we will adopt this division here.

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* From the Latin "senescere"—to grow old.

† Mitosis, from the Greek μιτόω—to put up threads (μίτος—thread); Karyokinesis, from κάρυον—see note ‡, p. 55, and κινέω—to move, stir, change.

The Preparation for the Division.—The first sign that a resting nucleus is about to divide is given by the centrosome which, as was already mentioned on page 59, usually appears at this period, even if it was not discernible in the resting cell. Originally one minute body, it now appears to be composed of two lying closely side by side and in the centre of an exceedingly delicate, colourless radiation, extending for a short distance into the surrounding protoplasm (Fig. 1). The two centrosomes gradually move away from one another, taking the radiation with them, in such a manner that each forms the centre of a separate figure, while the rays extending between the centres become drawn out into a distinct spindle-shaped structure.

During this process the chromatin of the nucleus has undergone certain changes. The original irregular network of fibres first becomes transformed into an unbranched, fine, apparently continuous thread of chromatic substance, which runs through the mass of the nucleus in numerous narrow coils (Fig. 1). It gradually contracts, the number of coils becoming smaller, while the diameter of the thread increases. Finally, the latter loses its continuity and breaks up into a number of pieces about equal in size, which are at first irregularly arranged within the nucleus, but gradually assume the shape of angles, and withdraw to a plane which stands perpendicularly to the long axis of the cell at about its middle (Fig. 2). These angular pieces of the chromatic thread are henceforward called "**Chromosomes**"*. Probably they also contain the paranuclein of the nucleoli; for these become entirely lost to view during the formation of the thread, and there is as yet no positive evidence as to what has actually happened to them. The nuclear membrane also, which in the resting nucleus is easily recognisable, has grown fainter and fainter until no visible trace of it is left; this usually is the case when the segments of the chromatic thread shift toward the middle plane of the cell; they now seem to lie free in the protoplasm (Fig. 2).

Meanwhile the centrosomes have continued their movement apart and have eventually reached a place where they stand directly opposite each other at the ends of the long axis of the cell (Fig. 3). The radiation starting from them is now very clear, more especially the fibres which run from the one centrosome to the other and are supposed to consist of the Linin of the resting nucleus. These fibres, in their entirety, form the "**Spindle**", a somewhat thick, spindle-shaped figure, in the middle of which the chromosomes have taken their position in a plane which stands at right angles to the axis of the spindle. Within this plane they arrange themselves in such a way that the angles lie axially while the free ends point outwards (Fig. 3). This arrangement is clearly seen only in the direction of the axis of the cell (or the spindle) and, as it presents the picture of a star, the whole stage has received the name "**Aster**"†.

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* Greek, from χρῶμα—see note *, p. 57, and σῶμα—see note *, p. 59.

† ’Αστήρ, Greek—star.

At about the time when it is formed a very important new change occurs in the shape of a **longitudinal division of the chromosomes**. Solid at first, these ever more sharply present themselves as two thinner threads lying closely side by side (Fig. 3). It even sometimes appears as if the Linin-fibres of the spindle also became discontinuous in their middles and their broken ends attached to the half-chromosomes of the respective side. The phases gone through up to the formation of the star composed of the doubled chromosomes represent the preparation for the division.

The Metakinesis *.—What follows now is very significant. It would appear as if the spindle-fibres begin to shorten and drag the half-chromosomes with them towards their centrosome — in any case, the halves of every chromosome-pair, thus far lying closely one along the other, separate. The process begins at their angles which bend asunder towards the centrosome of their side, the remaining parts gradually following (Fig. 4). In this way the original star becomes dissolved into two, each of which now consists of single chromosomes pointing with their angles towards the centrosomes. The original "mother-star" has thus become separated into two "daughter-stars"; the Aster-stage has passed into the so-called "**Diaster**"- or "**Amphiaster**"-† stage (Fig. 5).

It is not difficult to see that by the formation of the daughter-stars the chromatin of the original nucleus is divided into two **exact** halves; the breaking up of the mother-star into two is indeed the most essential phase of the whole division-process and from the "translocation" of the chromatin con-

* Μετακίνησις, Greek—translocation.

† Greek, from δίς—twice, double, or ἀμφί—on both sides.

nected with it has received the name Metakinesis. What still follows is simply the reverse of the preparatory process which led to the formation of the Aster, and is what we mentioned already as

The Reconstruction of the Nuclei.—The radiation originating from the centrosomes becomes fainter and finally disappears; the chromosomes lose their regular star-like arrangement (Fig. 6, upper cell) and, later, their thread-like shape by sending out lateral processes (Fig. 6, lower cell), until there is again the network of fibres characteristic of the resting nucleus. During the same time the nucleoli reappear as separate structures (Fig. 6, lower cell), and the nuclear membrane becomes again visible. The centrosomes, on the other hand, disappear.

Division of the Cytoplasm.—Unlike the nucleus, the cytoplasm divides in a much simpler way. At about the time when the daughter-stars have drawn near their centrosomes the cellular body shows a median constriction which is soon followed by the appearance of a distinct line of demarcation crossing the cell between the two daughter-nuclei. Along this line the division of the cytoplasm becomes perfect soon afterwards. As to the subsequent growth of the daughter-cells see page 69.

These are the main facts observable during the mitotic or karyokinetic division of the nucleus. There are variations in details in the various organisms, but the principle is, so far as we at present know, the same everywhere. A very interesting fact which seems to me to be worth mentioning here is that the number of the chromosomes is constant in all the dividing cells of one and the same organism, but may vary in different organisms. The figures thus far observed lie between 2 and 168; an organism, therefore, which in one cell of its body possessses e.g. 48 chromosomes has the same number in all its other cells; in Man, the respective number seems to be 24. Also the shape of the chromosomes may vary, but seems to be characteristic, at least, of certain groups of organisms.

In a large number of small and lowly organised Protozoa, carefully studied within recent years, the chromosomes become so minute and indistinct that it is often difficult to decide whether the respective divisions are mitotic or amitotic; thus, according to the present state of our knowledge, the two forms of nuclear division are not sharply separable.

3.—THE "MULTIPLE" DIVISION OF THE CELL.

We use this term for a process which thus far has chiefly been observed in various groups of Protozoa, but occurs in a typical form also during the early development of certain multicellular animals; this latter point will be returned to on page 430. The main feature of "multiple" division, as indicated by the name, is that the dividing cell breaks up, not only into two portions, as in the cases of "simple" division hitherto discussed, but into a larger number of portions at one and the same time. The nucleus, of course, takes the lead, in this form of division, as it does in the simple division; in other words, it is the first to break up into portions, and by the number of these determines the number of daughter-cells to be formed by the mother-cell. Just before the accomplishment of every multiple division the mother-cell is therefore for a time "multinuclear".

Apart from these common features, the process of multiple division shows some variations, which are due to the special behaviour of either the nucleus or the cytoplasm. The latter, e.g. may be entirely consumed in the formation of the daughter-cells, or it may not. In Figures 6–8, Plate II, we see illustrations of a multiple division which occurs at times, besides the ordinary division into two, in certain parasitic Amoebae of Man (see p. 68f and, later on, p. 151f). Figure 6 is the multinuclear stage ; the small nuclei subsequently draw nearer to the surface of the body, and incisions in the outline occur between them (Fig. 7) ; these grow deeper and deeper, until in the end they cut the whole cytoplasm up into sections, each of which encloses one of the nuclei, and together with this represents a young daughter-Amoeba (Fig. 8 ; note that the cysts surrounding the animals in Figs. 7 and 8 do not occur in the process here at issue, but in another to be dealt with on p. 151). Similar multiple divisions, as we shall see later, also occur in the life-histories of *Gregarina* (p. 135) and *Plasmodium* (pp. 140, 143) ; here, however, the process differs from the one described in the fact that only a part of the total bulk of cytoplasm present in the mother-cell is utilised for the formation of the daughter-cells ; the rest remaining unused and being left behind as a (subsequently decomposing) "residual body" (for further details see especially p. 135).

The multinuclear stage which, as we have seen, precedes the multiple division of the cytoplasm, may arise in two essentially different ways. By far the more common of these is that the originally single nucleus divides by mitosis into two, that the daughter-nuclei divide again, and so on, until the final number is reached. In these cases we therefore have a multiple division of the cell preceded by repeated ordinary or "simple" divisions of the nucleus ; for special examples see pages 135, 140, 143, and 430. In other (rarer) cases, the chromatin is seen to gradually accumulate along the surface of the nucleus and there to separate into a number of portions (Fig. 5, Pl. II). By a subsequent rupture of the nuclear membrane, these become free and then appear in the cytoplasm as independent daughter-nuclei. By this process, therefore, the nucleus would simultaneously break up into the latter, and we accordingly would have a multiple division of the nucleus. As an example of this form of nuclear division the above-mentioned parasitic Amoebae of Man are usually quoted (Figs. 5 and 6, Pl. II); it must, however, be pointed out that the existence of the process in the form described is quite recently being contested; for further details see page 151.

4.—THE "REDUCING" OR "REDUCTION-DIVISION" OF THE NUCLEUS.

When speaking of reproduction in general we pointed out that every organism takes its origin from a single cell (p. 43). In the multicellular organisms this cell is called the **Egg-Cell** and is produced by "**female**" individuals. In many lower animals it is capable of developing into a full-grown new member of the species without the interference of another individual; I may here mention at once that we scientifically call this phenomenon "**Parthenogenesis**" *. In the higher organisms, on the contrary, the egg-cell, in order to become able to transform into a new organism, must be "**fertilised**", i.e. it must unite with a corresponding cell (the "**Spermatozoon**"†) produced by a "**male**" individual. We shall have to study the process of fertilisation later; what interests us here is that the egg-cell, before it is fertilised, undergoes a series of changes which we combine under the denomination "the maturation of the egg-cell". Previous to these changes the egg-cell is "immature", and, by the changes, makes itself ready, so to speak, for being fertilised. The changes themselves consist in the removal of certain parts of the nucleus, and take place by mitotic division of the latter, followed by an unusual division of the cell. These transformations going on in the egg-cell find an interesting parallel in the development of the spermatozoa; so we will include this in our description.

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* Greek, from παρθένος—maiden, virgin, and γένεσις—production, birth (see also note *, p. 53, and note †, p. 401).

† Greek, from σπέρμα—seed, germ; and ζῶον—see note †, p. 60.

The Maturation of the Egg-cell (Figs. 1-6, Pl. VI).—Before going into details I must mention that the phenomena I am about to explain usually take place before fertilisation; but there are cases known where they coincide with it and there is the probability that they may even follow it. The process itself has been studied in many egg-cells, but is especially clearly observable in those of *Ascaris megalocephala*, a large round worm living in the intestine of the horse and having cells characterised by the presence of four chromosomes (compare, about the number of these, p. 111). Its egg-cells develop from cells which we practically term "**Oogonia**"*, but might also call "egg-mother-cells"; these first divide (mitotically) many times, thus gradually yielding a very large number of descendants which eventually cease dividing, but, instead, each increase somewhat in size, and in this state represent an "immature egg-cell" or an "**Oocyte**"†; by the changes to be described hereafter,

* Greek, from ὠόν—egg, and γονεύω (or γονέω)—to produce.

† Greek, from ὠόν—egg, and κύτος—see note †, p. 55; the term thus designates the individual cell, from whith the mature egg-cell arises.

the oocyte transforms itself into the "mature" egg-cell. The changes themselves are these.

When an oocyte has almost reached its full size its nucleus divides by mitosis, the four chromosomes being doubled by longitudinal fission and each daughter-nucleus receiving four such halves (Fig. 1). During the metakinesis the nucleus shifts its position towards the surface of the cell (Fig. 2) and what happens now is that particular form of "budding" alluded to on page 107. The four daughter-chromosomes which lie nearest to the surface protrude out of the latter, taking a small quantity of protoplasm with them, and become in the end totally separated from the egg-cell, lying as a minute body close to it (Fig. 3). While, then, the nucleus has been reduced to half of its former mass, the cytoplasm has only given up a quite insignificant part of its bulk.

Under ordinary circumstances the four remaining chromosomes would now have to grow to their original size before becoming able to divide again (see pp. 111, 69); in the present case, they do not, but without growing, even without reconstructing themselves, they at once undergo a second division preceded by a division of the remaining centrosome. There is not even the longitudinal halving, and hence each grand-daughter-nucleus can only receive half of the four entire chromosomes. The two groups of two thus arising are already seen to begin their movement apart in Figure 3, and are completely separated in Figure 4, guided by the centrosomes. One of the groups of two is subsequently removed from the cell, in the shape of a second small body (Fig. 5), in exactly the same way as previously were the four chromosomes in the first body. In the case of *Ascaris megalocephala*, the latter does not change further, while, in other egg-cells, it also breaks up into two halves, each of course with half the previous number of chromosomes.

In this modified state, the egg-cell is "**mature**", i.e. ready for being fertilised. Its nucleus now contains **only half the original and normal number of chromosomes** and outside, close to the cell-surface, there lie two minute bodies, one containing, within a scanty layer of protoplasm, four chromosomes, the other two chromosomes : the removed parts of the nucleus. Since in the other cells above alluded to the former body is also halved we have in these cases **three** small bodies which each contain half the normal number of chromosomes. These bodies have been known under the name "**Polar Bodies**" for a fairly long time, but it was not until comparatively recent years that we had any information as to their true nature.

The main facts just described obtain in all animal egg-cells, the maturation of which has thus far been studied, and even in the egg-cells of plants ; with regard to details, however, numerous variations occur which, despite the general biological interest they offer, cannot be discussed here.

The Development of the Spermatozoa (Figs. I-VI, Pl. VI).—This has been carefully studied, with regard to the details here at issue, in the same worm, the maturation of the eggs of which has just been described. In order to obviate erroneous conceptions I will mention that these spermatozoa do not present the shape usual among the animals (see p. 171), but are cells capable of slight amoebic movements and enclosing a conical body of some solid, strongly refractive substance (as represented below and to the left in Fig. 1). They develop in a way quite similar to that of the egg-cells, namely, from "**Spermatogonia**"*, or "sperm-mother-cells", which, by repeated ordinary mitotic divisions, yield a large number of "**Spermocytes**"*, while these, in their turn, eventually supply the spermatozoa.

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* Greek ; formed from σπέρμα and γονεύω after the same fashion as "Oogonia".

The spermocytes, just as the oocytes, originally possess each four chromosomes which, however, become halved longitudinally at a very early period, so that at the beginning of the process here to be described eight chromosomes are already present as visible in Figure I; they now move asunder to form two groups of four attracted by the centrosomes (Fig. II), the separation being followed by the division of the cell which breaks up into two equal halves (Fig. III). Even before this has come to perfection the centrosome of each daughter-cell divides again (Fig. III) and a **second** division follows the first so quickly that the chromosomes have no time to double their number by longitudinal fission, but become instead **separated into two groups of two** in exactly the same manner as we saw in the second division of the maturating egg-cell (the process will be understood from a comparison of Figs. III, lower cell, IV, and V, with 3, 4, and 5). The four cells which thus arise from each sperm-mother-cell are all equal in size and have each two chromosomes. These are at first clearly recognisable, but become subsequently blended into one apparently solid chromatin-grain (Fig. VI). The four cells are the spermatozoa. Like the mature egg-cells they accordingly possess each only **half** that number of chromosomes which is characteristic for all the other cells of the body.

A comparison of the methods by which the two kinds of sexual cells "maturate" indeed yields the interesting result that they only differ in so far as the behaviour of the cytoplasm is concerned; for this is equally divided into four parts in the spermatozoa, but remains almost undivided and with one of the four nuclei in the egg-cells. If, on the contrary, the behaviour of the karyoplasm is considered maturation of egg and spermatozoon are identical, quite especially in those cases where the first polar body, in concomitance with the formation of the second, also divides, thus bringing the total up to three. As a common character of egg and spermatozoon in their mature condition we therefore have their possessing only half the ordinary number of chromosomes, and, as this halving takes place in the second of the two consecutive nuclear divisions above described, we call this division "reducing" or "reduction"-division. We also see that by the union of an egg-cell with a spermatozoon the original and normal number of the chromosomes will become restored (Fig. 6); but this is a subject the discussion of which we must still postpone for some time.

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* Greek; from σπέρμα and κύτος after the same fashion as "Oocytes" (note †, p. 115).

5.—THE DIVISION OF THE CYTOPLASM.

It has been pointed out as a striking difference in the development of egg and spermatozoon that, in the latter, the divisions of the mother-cell are **equal**, i.e. lead to the formation of daughter-cells of the same size, while in each division of the egg-cell one half of the nucleus only receives an insignificant portion of the cytoplasm and the other half all the rest. Owing to this unequal repartition of the cytoplasm we call this type of cellular division **unequal** division. We already found it in the process of budding and will meet with it again when discussing the segmentation of certain egg-cells (p. 426). Both the equal and unequal divisions are modifications of what we call **total division** of a cell, because in either process the cytoplasm is completely split up into the two daughter-cells. This is no longer the case in certain egg-cells, where several early divisions of the nucleus are only followed by the formation of clefts extending somewhat into the cytoplasm but leaving the greater part of it undivided. In these cases, we therefore only have a **partial division** of the cytoplasm. We shall return to this phenomenon in the chapter on the embryonic development (p. 418f).

6.—THE SIGNIFICANCE OF THE VARIOUS FORMS OF NUCLEAR DIVISION.

If we now review the facts above related there can be no doubt that **the multiplication of the cell is controlled by the nucleus**, the division of which, without any exception, precedes that of the cytoplasm. In the amitotic division, no particular care is apparently taken to divide the nuclear matter exactly into halves: the complicated phenomena occurring during **karyokinesis**, on the other hand, are obviously a method for **precisely halving the chromatin**, not only as regards its **quantity**, but quite especially as regards its **quality**. It seems most suggestive in the latter respect that in the beginning of the division the chromatic matter should be arranged just in the form of a long and thin **thread** and that this thread should subsequently be **halved longitudinally**. For let us only suppose that the chromatin, instead of being absolutely the same throughout, be made up of many slightly different varieties. It is then imaginable that in a thread these become arranged in such a way as to form a more or less continuous series of transitions from one end to the other, and it is equally obvious that if such a thread is halved longitudinally each half must contain a part of each variety — even the slightest — while in any more bulky arrangement it might easily happen that certain varieties remain as a whole with one half and others with the other. If we contemplate the facts observable under the microscope, there seems indeed no doubt possible but that the elaborate process of **karyokinesis is a means to qualitatively and quantitatively divide the chromatin of the nucleus into two precise halves.**

Immediately after a division the quantity of chromatin in a daughter-nucleus is of course half that of the mother-nucleus ; but we have already seen (p. 69) how the vital activity of the living substance is able to replace anything lost in a division by corresponding material newly manufactured. Thus, during a series of karyokinetic divisions, the quality of the chromatin is passed on to all the descendants of the original cell.

An important exception to this rule is made in the reduction-division. To exclude any mistake let me here again point out that the nuclear division which immediately precedes it (Figs. 2, 3, and II, III) would not differ from an ordinary mitotic division if the daughter-chromosomes were allowed time to grow again to their normal size ; at any rate, these chromosomes do not substantially differ, either in the two daughter-cells, or in these and the mother-cell. This is not the case in the second division by which the entire chromosomes are separated into two groups. According to what was said above about substantial varieties probably present in the original chromatic thread, it is obvious that in the mature egg-cell some of these varieties must have been altogether removed from the cell, while in the spermatozoa they are still all present but apportioned to different individual specimens.

There now naturally arises the question why, in the division of the nucleus, such extraordinary care should be taken to ensure an exact halving of the chromatin in contradistinction to all the remaining constituents of the cell, which also become divided, but, so far at least as we at present know, none of them in a similarly complicated way. The bare fact of the elaborate division of the chromatin suggests that the maintenance of its quality during the divisions must be of vital importance both to the parent cells and to the descendants; it only remains to be found out wherein this importance consists. A very conspicuous fact repeatedly emphasised in the preceding discussions is that the offspring of a cell, as a common rule, again presents the aspect and structure of the parent cell. Combining this fact with the one here under consideration we must conclude that the chromatin, as it is most carefully handed over to the descendants, so also determines the biological similarity of these descendants, either alone, or in association with other parts of the cell. The definite answer to the alternative which here still presents itself is given by a biological process known as "sexual reproduction", to the description of which we will now turn.

CHAPTER VI.

On the Reproduction of the Animals.

We now know the various methods by which the cell may divide and thus undergo multiplication. Although all these methods are primarily cytological* processes, i.e. phenomena associated with the life of the cell, they assume a fairly different significance if we consider them from the general biological point of view. In the multicellular organisms, e.g., the cellular multiplication only leads to growth, that is, an increase in the size of an already existing individual and, additionally perhaps, to an increase in the complexity of its organisation. In the unicellular organisms, on the contrary, the same process leads to the formation of new individuals of the race and thus turns into a method of reproduction. We know this from *Amoeba* and *Vorticella*; the most outstanding feature is that in these (and other) cases, the production of descendants can be accomplished by any individual without the interference of any other. In Biology we call a reproduction of this sort quite in general an "**Asexual Reproduction**".

From what has just been said it might appear as if the growth of the multicellular and the asexual reproduction of the unicellular organisms were two quite different biological processes. On closer scrutiny, however, it is found that this is not exactly the case. For, as they both rest on the same cytological phenomenon, so in practice they also show a number of "connecting links" between each other; we shall indeed see in due time that growth, in multicellular organisms, not infrequently results in asexual reproduction (see e.g. p. 417), while the latter, in unicellular organisms, occasionally leads to the formation of stages which foreshadow the conditions in the multicellular (p. 407f). For the present we have to point out another very important peculiarity of asexual reproduction.

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* See note †, p. 55.

Very carefully conducted experiments of older and more recent date have shown that asexual reproduction cannot go on unlimitedly; at any rate in animals, while a few exceptions to this rule seem to exist among the plants (see here the Bacteria, p. 305 and also p. 382f). Thus when we take some individual Protozoon and separate its daughter-individuals as soon as a division has taken place, and again do the same at every new division while keeping the animals under favourable conditions for the whole time of the experiment, we shall see that hundreds of such divisions may follow one another without visible detriment to the organisms. Nevertheless, a time is sure to come, sooner or later, when these commence to show signs of degeneration which, becoming more intensified in every new division, in the end lead to the death of the individuals before they divide again. Large as their power of dividing may be it yet has its limits. If, on the other hand, we bring two or several individuals together at about the time when the signs of degeneration commence to appear it will be found that the animals, which took no perceptible notice of each other previously, now more or less eagerly unite in pairs, remain so for some time, and then separate again, to resume their multiplication by division with the old intensity. It is obvious therefore that this union has given them new dividing power, that it meant for them, we may say, a "**Renewal of Vitality**" or a "**Rejuvenescence**".

The process here sketched, that is, the union of two different individuals for the purpose of propagating the race, is in scientific language termed "**Sexual Reproduction**" and is, with the few apparent exceptions above alluded to, common to all organisms. Although in essence the same everywhere, it may vary in certain external details to which we shall return presently; there are, in addition, several most interesting differences which concern its relations to the asexual reproduction. In all higher animals, sexual reproduction is the only mode of reproduction; in many lower animals and a very large number of (higher and lower) plants, sexual and asexual reproduction exist side by side; examples will be supplied by *Hydra* (p. 416f), certain relatives of the earth-worm (p. 473) and various plants (pp. 380ff). Finally, a number of other animals and plants are also capable of multiplying both sexually and asexually, but in such a way that the two modes more or less regularly alternate with one another; the life-history of the respective forms then assuming that particular course which scientifically we term "Heterogony"* (pp. 146, 196ff).

1.—Sexual Reproduction.

After these general introductory remarks let us somewhat more fully investigate sexual reproduction. It was hinted above that, though intrinsically the same in all cases, it yet shows variations in details. According to these differences we distinguish three types. In all **multicellular** organisms, the uniting elements are not the organisms proper, but **cells** of their bodies specially delegated for the purpose of reproduction. They show among themselves a great difference in their external attributes, in so far as there are "male" cells, the "spermatozoa", characterised by small size and more or less pronounced mobility, and there are "female" elements, the egg-cells, characterised by large size and immobility. These differences are usually described as the "**Sexual Distinctions**" of the propagative cells. The process of the union of an egg-cell with a spermatozoon is in scientific language the "**Fertilisation**" of the egg-cell.

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* Greek, from ἕτερος—see note *, p. 53, and γονέω—see note *, p. 115. The term lays the chief stress on the different manner in which the successive generations are produced.

In all **unicellular** organisms, the uniting cells are **entire individuals.** In a large number of cases, their union leads to a complete and definite fusion of their bodies; in this case we speak of "**Copulation**"; the copulating individuals may be equal or unequal in their external appearance and, in the latter case, may exhibit a more or less pronounced resemblance to egg and spermatozoon. These cases are of a high biological interest. In other forms, the union of two individuals is only **temporary**; they separate again after the union. In these cases, we speak of "**Conjugation**": the conjugating individuals are nearly always inwardly and outwardly alike. This latter mode of union is in all probability the older and more original, so we will consider it first.

A.—**Conjugation** (Plate VII).

This process has been very carefully studied in certain members of the genus *Paramaecium*; so we will take this as our example. As to the aspect and general structure of *Paramaecium* details have been given on page 98f; I here especially remind you of the presence of two nuclei, the "macronucleus" and the "micronucleus", which I said were of "different biological value for their owners". This assertion will be borne out by the facts described hereafter.

Under ordinary circumstances the Paramaecia multiply by division which takes place at right angles to the long axis of the body (Fig. 7, Pl. III). The two nuclei divide first, the macronucleus directly, the micronucleus by mitosis which, in this case, presents a singular feature inasmuch as the two daughter-nuclei remain united by a thin strand of substance even while moving apart, thus presenting the aspect visible in Fig. 7, Pl. III, and also Figs. 2, 3, 5, Pl. VII. While the new nuclei move apart the cytostome becomes doubled and a second contractile vacuole is formed anew near each of the two already in existence (*cV1* II and *cV2* II, Fig. 7, Pl. III). These preparations being accomplished, there appears about the middle of the body a transverse constriction which grows deeper and finally completely separates the animal into two daughter-individuals. Just before the separation takes place these present the interesting appearance of a pair of complete and normally built, but only somewhat smaller specimens attached, the one with its anterior end to the posterior end of the other in a straight line.

The inclination to conjugate usually seizes a large number of, perhaps even all, individuals of an artificial culture at about the same time ; thus when once conjugating specimens make their appearance in a culture the couples soon occur in such numbers that observers have been led to speak of **"Epidemics of Conjugation"**. In the conjugated state the organisms lie against each other with their ventral aspects in such a way that the cytostome of the one covers that of the other (as visible in Fig. 4, Pl. VII). The capability of adhering to one another is brought about by certain changes in the pellicule which becomes sticky ("miscible", as it has been termed) and is later completely dissolved in an area behind the cytostome, a "bridge" of continuous protoplasm being thus formed between the two individuals (note the interruption in the line which separates the two individuals in Fig. 3). With the formation of this bridge the part played in conjugation by the cytoplasm is finished: the other changes exclusively concern the nuclei.

The **macronucleus** (*Ma* in the Figures), to state that at once, **perishes** during (or after) the process; its originally rounded or oval shape becomes irregular by the formation of numerous bulgings, which more and more isolate themselves from the main part, and finally become perfectly detached. Others form in their place, and thus the whole macronucleus is gradually broken up into several dozens of small pieces scattered about in the cytoplasm (Figs. 5, 6). They subsequently slowly decrease in size, apparently owing to dissolution, and in the end disappear. The macronucleus is thus destroyed in the act of conjugation.

The **micronucleus** (*Mi* in the Figures), meanwhile, has first become considerably swollen (Fig. 1) and has, then, undergone two mitotic divisions, one immediately in the wake of the other (Fig. 2). Of the four micronuclei thus arisen in each individual, **three perish**; they move somewhat aside and become lost between the fragments of the macronucleus ($\frac{Mi}{4}$ in Figs. 2, 3, 4, 5). The fourth which is preserved—it seems always to be the one which happens to lie nearest to the bridge—divides once more. It is very probable that this division is of the reducing type, i.e. that each of the daughter-nuclei only contains half the normal number of chromosomes; in any case, these daughter-nuclei behave in a very singular manner, for one of them begins to shift its position through the bridge over into the other individual, and so does the corresponding daughter-nucleus of this individual (Fig. 3; in order to henceforward distinguish the nuclei of different origin those of the one individual are painted entirely black, those of the other dotted); the result thus is an **exchange of half of their actual nuclear material between the two conjugating specimens.** With the perfection of the exchange the purpose of the whole process is evidently accomplished, for the bridge now becomes broken, the skin again covers the naked areas, and the individuals finally separate.

Each has now, apart from the fragments mentioned above, two half-micronuclei, one of which is its own. while the other is derived from the associate (Fig. 4, ♂ and ♀ * in the individual to the left). These two halves subsequently unite into a single nucleus (Fig. 4, *N* ⚥ in the individual to the right), the further conduct of which varies somewhat in different species. In principle, it divides, in the usual manner, into two daughter-nuclei ($\frac{N}{2}-\frac{N}{2}$ in Fig. 5), one of which, by gradually swelling up and imbibing fluid, transforms into a new macronucleus (*Ma*+, Fig. 6), while the other remains small and represents a new micronucleus (*Mi*+ Fig. 6). The variations alluded to consist in the fact that the original nucleus *N* ⚥ does not divide once only, but twice, or even thrice, thus giving rise to two (or four) macronuclei, and a corresponding number of micronuclei. By subsequent divisions of the cytoplasm these multinuclear individuals yield specimens which each have only one macronucleus and one micronucleus left. The original structure of the species is thus restored, but the substance the animals consist of is no longer the same as before conjugation. **The nucleus has ridded itself of a part of its former mass and has received in its place nuclear material of another individual;** it is, to all appearance, exclusively this nuclear material which is taken up in conjugation.

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* These signs, very often used in Biology, indicate, ♂ the male sex, ♀ the female sex; the sign ⚥ accordingly means male+female.

From the facts here described several important conclusions can be drawn. The passive conduct and ultimate destruction of the macronucleus show that this nucleus has nothing to do with the sexual process; the formation of a new macronucleus after conjugation, on the other hand, shows that a nucleus of this sort is necessary for the organism. So we interpret the **macronucleus** as **an organ which controls the functions of life during the period between two conjugations**; in other words, it controls what we formerly called the "household-work" of the organism, and is in accordance with this function often termed the "vegetative nucleus". The **micronucleus**, on the contrary, **is the "sexual nucleus"**; it is suggestive that it always divides by mitosis and thereby hands its chromatin down, in the way described on page 120f, to all its descendants, until a part of it is finally exchanged with that of another individual in conjugation. The fact that the micronucleus produces the macronucleus shows that the two nuclei are not fundamentally different; we see in their separation the result of a division of labour, in so far as what in other cells is incumbent upon a single nucleus, namely, the "vegetative" and the "sexual" functions, is here distributed between two.

It has already been pointed out that in the case of *Paramaecium* the aspect of the conjugating individuals is the same; these therefore have no "sexual distinctions" (see also pp. 163ff). Nor do the nuclei which escape destruction exhibit any noticeable differences; it even appears that there are none between the resting and the migrating portions of the same nucleus, the question which has to wander and which to remain simply depending on which happens to lie nearer to the bridge. There thus remains the only difference that one actually moves, while the other remains stationary. I have stated above that mobility is a character of the "male" germinal element, immobility one of the "female"; for this reason we consider the **wandering half** of the micronucleus as the **male equivalent**, the **resting half** as the **female equivalent**. By their union the new nucleus is formed.

B.—Copulation.

When speaking of Vorticella, I mentioned the fact that at certain times small individuals arise which finally each settle on a larger and fuse with it, protoplasm with protoplasm, nucleus with nucleus (p. 94). The last-mentioned detail in especial will remind you of what you have just heard about conjugation in *Paramaecium ;* as a matter of fact, the process described in *Vorticella* is the "sexual reproduction" of these organisms, which differs from that of *Paramaecium* in two details. One of these is that the uniting individuals show outward distinction (one being small, one large), the other that they do not separate again but fuse into one. The former becomes easily comprehensible if we recall to our minds the habits of Vorticella. We know that this organism is fixed to the spot by the stalk; the individuals are thus prevented from seeking each other unless some at least make themselves free. After what we have learned about the differences between the male and female equivalents we will not be surprised to see that the males acquire this mobility. They, moreover, are smaller than the females, originating as we saw on page 94, from a normal individual undergoing several divisions in quick succession. If you compare the Figure 4 of Plate III, showing this division, with the Figure VI of Plate VI, in which the development of the spermatozoa of *Ascaris megalocephala* is represented, you will at once notice the resemblance between the two processes. Although there are as yet no special observations, it is very probable that during the formation of the Vorticella- males a reduction of their chromatin takes place, just as in the spermatozoa and, in a somewhat modified form, in the copulating Paramaecia.

In the explanatory remarks on page 126, I stated that the sexual process which leads to a complete and definite fusion of the two uniting specimens is technically called copulation; so we have, in Vorticella, no longer a "conjugation", as is the rule for the Ciliata, but a "copulation" brought about, as an exception to the rule, by the limited mobility of the Vorticellae.

In other unicellular organisms copulation is the normal sexual process and the uniting individuals, as already hinted on page 125, show more or less marked "sexual distinctions". I will here demonstrate the process of copulation by two examples, one in which these distinctions are but little pronounced, and another in which they are so great that the male and female equivalents—in this case whole organisms—almost completely foreshadow the picture offered by egg and spermatozoon in the multicellular organisms. Both examples, at the same time, will make you acquainted with a new Class of Protozoa, some members of which have recently gained an extraordinary practical importance. The Class has the scientific name "**Sporozoa**", and its distinctive character is the formation of "spores". What these are we shall see in due time (see p. 137). We take our first example from an Order called "Gregarinida", a name derived from the chief representative genus:

Gregarina (see Plate VIII).—These organisms have a definite and very characteristic shape. The body is in the main cylindrical or slightly spindle-shaped (i.e.

somewhat thicker in the middle than towards the ends) with rounded extremities. The cytoplasm is very granular and surrounded by a thin layer of ectoplasm which in its turn is covered by a thin pellicule (Figs. 1-4). In a number of forms the hyaline ectoplasm forms a kind of partition-wall which extends through the entoplasm and sharply separates an anterior, smaller, from a posterior, larger portion of the body (Figs. 2-4). These are distinguished from each other by the names "Protomerit" and "Deutomerit" * respectively. The transparent, round or oval nucleus, enclosing one or several easily visible nucleoli, usually lies near the centre of the body and, if there is a partition-wall, in the Deutomerit. According to the presence or absence of this wall the original genus Gregarina has been divided into several with separate names. If there is no partition-wall we speak of "*Monocystis*"† (Fig. 1); if it is present we speak of "*Gregarina*" ‡ in the narrower sense (Fig. 2). In some very interesting Gregarinida the Protomerit further bears on its anterior aspect a more or less long stalk-like process which at its tip may be armed with hooks ; this form is distinguished by the name "*Stylorhynchus*" § (Fig. 3).

These Gregarinida live in the intestine or the abdominal cavity of various animals, and feed on the fluids there present. I will here provisionally mention that we call organisms living and feeding after this fashion "**Parasites**" ¶ ; as we are going to consider them from a general biological point of view later (see pp. 288ff) I here limit myself to the statement that their chief characteristic lies in the fact just mentioned, viz. that they obtain their food, more or less ready-made, from other living organisms which are biologically termed their "**Hosts**". The Gregarinida, then, are "parasites", because they live in, and obtain their food from, other living animals. As this food is already liquefied it can directly be absorbed through the skin. The Gregarinida. therefore, do not require any separate mouth, and practically have none, just as we saw in *Opalina* (see p. 97) which lives under exactly similar conditions and is thus also a "parasite". Some Gregarinida are very sluggish and only move by a slow, even gliding; others are more mobile and change their form by frequent contractions and extensions (due to the presence of myonemata; see p. 83). These few statements, in connection with the drawings, may suffice to give you an idea of the external shape, the structure, and the habits of the Gregarinida: we now turn to their biology which chiefly interests us here.

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* Greek, from μέρος—part, portion, and πρῶτος—see note*, p. 46; δεύτερος—the second.

† Greek, from μόνος—single, alone, unique, and κύστη—see note *, p. 70.

‡ From the Latin "grex", genit. "gregis"—flock, because the animals, where they occur, usually occur in "flocks".

§ Greek. from στῦλος—pillar, shaft, style, and ῥύγχος—trunk (e. g. of the elephant), snout, muzzle.

¶ Παράσιτος, Greek, originally a man who "sits beside" somebody else (at table) ; later—spunger, parasite.

In examining animals which harbour Gregarinida it is not a rare occurrence to find among normal individuals such as described above others which by their anterior end adhere to the posterior end of a second individual, the two bodies forming a straight line (Fig. 4). Such connected individuals are preparing for copulation. They subsequently contract and secrete a sticky substance which gradually completely envelopes them and by hardening becomes transformed into a cyst (p. 71). Within this resistant envelope the two animals are at first clearly recognisable (Fig. 5); later, however, they undergo a series of changes the details of which are only discovered by very complicated and subtle methods of investigation. What happens is in the main this. The nucleus (of each individual) begins by disintegrating; its largest part becomes dissolved in the protoplasm and disappears (remember here what we have seen in the conjugation of *Paramaecium*); only a small part remains, and this, by alternate growing and dividing, in the end supplies a considerable number of small nuclei. Each *Gregarina* at this stage is therefore multinuclear (pp. 56, 112), and the cytoplasm, originally of fairly regular outline, has assumed a rather irregular, perhaps even branching shape. The small nuclei, at first irregularly scattered throughout it, subsequently draw near the surface (Fig. 6), and now there takes place what we previously described as "multiple division of the cell". Each of the small nuclei collects a small amount of protoplasm round it (Fig. 7), and thus forms a minute cell which in the end severes its connection with both its neighbours and the underlying cytoplasm. At this stage, each of the original *Gregarina*-individuals has transformed into a considerable mass of small cells forming a dense coat round that part of the cytoplasm which has not been used up in the process and now represents what we already described as residual body (see p. 113). The most remarkable feature, however, is that, despite the complete identity in shape and size of the original individuals, their descendants formed as just described show differences in shape and size (Fig. 8). These are still very trifling and difficult to recognise in some species, but are fairly evident in members of the genus *Stylorhynchus*. Here, the descendants of the one individual are round (Fig. 10), those of the other spindle-shaped and at their posterior ends even drawn out into a fine thread-like tail (Fig. 9), by the whipping movements of which the organisms are enabled to change their place, whereas the round individuals, destitute of these filaments, are practically immobile.

You probably have already noticed that, here, we again have those differences previously enumerated as the attributes of the male and female germinal cells; as a matter of fact, **these small cells of different aspect are the sexual stages of Gregarina.** It has been found necessary, for the purpose of comparison, to distinguish them, and the corresponding stages of other Protozoa as well, by a general designation; so they have been termed "**Gametes**"*; the mobile male stages, owing to their usually smaller size, being differentiated as "**Microgametes**", the less mobile, or completely immobile, female stages, owing to their usually larger size, as "**Macrogametes**". I may add at once that the mother-cells of the two forms of gametes, in the language of comparative Biology, are termed "Microgametocytes" and "Macrogametocytes" respectively † (compare here the terms spermocyte, p. 118, and oocyte, p. 115).

The **gametes** of *Gregarina*, after having fully developed, **proceed to copulation**. The microgametes each approach a macrogamete and fuse with it, the cellular bodies first and nuclei afterwards. In the end, there is again a complete cell with nucleus and cytoplasm, which by no sign indicates that it is inwardly made up of the bodies of two different cells; it is scientifically termed the "Copula" or "**Zygote**" ‡. The zygotes surround themselves each by a cyst of its own (Fig. 11) and we then have, in every large cyst, in place of the two *Gregarina*-individuals attached to each other as in Figure 5, a large number of small cysts, between which there is a crumbling granular mass, the two gradually disintegrating residual bodies.

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* Greek, from γαμέω—to marry, to become married.

† Meaning the "cells" (κύτος) from which the respective gametes take their origin (see also note †, p. 115, and note *, p. 118).

‡ "Copula", Latin, from "copulare"—to join, to tie together; "Zygote", Greek, from ζυγόν—yoke, in the sense of "a pair" (e.g. a "yoke" of oxen), to indicate that the respective stage owes its origin to the fusion of "a pair" of individuals.

This developmental stage of the various Gregarinida had been seen by earlier observers long before its true nature was known, and various names were given to it. The small cysts, for their resemblance to the spores of certain plants (see about these p. 248), were called "**Spores**"[*], a name they have retained up to the present day. Many Protozoa other than the Gregarinida multiply by a similar process of "**Sporulation**" (i.e. "forming spores"), and owing to this common characteristic have been collected into the separate Class "**Sporozoa**"[†]. In some of these, the spores show a peculiar shape; thus, in the genus *Monocystis*, the members of which are common inhabitants of the seminal vesicles of earthworms, the spores have a regular spindle- or boat-shape (Fig. 12) and from this reason when first discovered were called "Pseudonavicellae"[‡]; the cysts containing them therefrom received the name "Pseudonavicelle-cysts". In many regions of Europe it is hardly possible to examine the seminal vesicles of an earthworm without finding these cysts more or less abundantly, for they seem to remain in place so long as their bearers live, whereas in the case of the other Gregarinida which live in the intestine of their hosts the cysts are usually evacuated with the faeces soon after their formation.

Within the spore, the zygote still undergoes a series of changes. The nucleus divides two or three times, being thus broken up into four or eight smaller nuclei. These somewhat withdraw to the surface and the cytoplasm then divides into a corresponding number of pieces becoming in this case entirely consumed in the formation of the daughter-cells which, when fully developed. present a slender spindle-shape and usually lie somewhat twisted round one another in the long axis of the cyst. their nuclei all at about the same level (Fig. 12).

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[*] Greek, from σπόρος (or σπόρα)—sowing, seed, germ.

[†] From σπόρος—see preceding note, and ζῶον—see note †, p. 60.

[‡] From ψεῦδος—see note*, p. 63, and "navicula"--a small boat.

These descendants of the zygote, from their being enclosed in the spores have received the general designation "**Sporozoites**" *. They are young Gregarinae. but remain unchanging until the spore is again brought back into the intestine of a host such as harboured the original Gregarinae. This return is easy in the case of spores which, as above mentioned, are evacuated with the faeces. The latter, in the course of time, become destroyed and mixed with the soil, whence the spores may accidentally be picked up with the food by new hosts which happen to come their way. In the case of the *Monocystis*-species, the spores of which are enclosed in the seminal vesicles, it appears that they become only free with the death and the subsequent decomposition of their bearers, but are then swallowed by other earthworms as before (see p. 471). In the intestine of a suitable host. the wall of the spore is broken and the sporozoites become free. They soon enter the epithelium-cells and there grow somewhat, feeding on the substance of the cell which is thus gradually destroyed. Later, they again leave the cell and pass over into the intestinal lumen within which they finally assume their definitive shape. This, in general outlines, is the life-history of the Gregarinida; there are many variations in detail, which. however, cannot here be entered upon.

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* Composed of the same words as "Sporozoa", but having quite a different meaning, as indicated by the different ending.

If we now shortly review this history, using the scientific terminology we have learned, it runs in this way : The full-grown animals, as they usually come under observation, are gametocytes (male and female) ; before breaking up into the gametes they encyst themselves, and these cysts must sooner or later leave the host. Within the cysts, the gametes are formed and proceed to copulation ; the zygotes, by division, furnish sporozoites which. in their turn, again develop into gametocytes, as soon as the cysts have been transferred into a fresh host of a suitable species.

We now turn to our second example :—

Plasmodium (Plate IX).—These organisms are extremely minute Sporozoa which live in the red blood-corpuscles of Vertebrates, and thus are again "parasites". They are scientifically classified into several Orders with numerous genera. Those which we are going to consider in particular are members of a genus *Plasmodium* ; they inhabit the erythrocytes of Man, and are the cause of " Malaria ", a disease widely spread, and claiming numerous victims, in almost all warm countries of the globe. It is chiefly characterised by vehement attacks of fever which, though of short duration by themselves, yet recur at very regular intervals of two or three days. After in this way having gone on for several weeks. they gradually cease ; but it may happen that new attacks re-occur after months, when the patients seem to have entirely recovered. Fuller particulars about this disease will be given to you later in your clinical lectures ; the few statements made above are necessary here to enable you to understand the biology of the organisms, which is the object of our present study.

If we examine the blood of a patient, in whom the attacks of fever repeat themselves every third day, several hours before the attack is due, we find in numerous erythrocytes extremely delicate foreign bodies: the organisms which interest us. They are, during life, very pale and difficult to see, but come into view by adequate methods of preservation and staining. We then distinguish (Fig. 1) a small particle of chromatin representing the nucleus and, chiefly to one side of it, the cytoplasm which, by its irregular outline, indicates that it is capable of slight amoebic movements. These young parasites averaging at first about a quarter, or a third, of the diameter of the erythrocyte, feed on the "hemoglobine", i.e. the coloured substance which gives the erythrocytes their peculiar tint. As this hemoglobine is thus destroyed by the Plasmodia, the attacked erythrocytes, as a matter of course, become gradually paler, while a large clear space and tiny granules of a brown pigment appear in the bodies of the Plasmodia (Fig. 2). The former is interpreted as a kind of food-vacuole, while the latter represent the indigestible remains of the devoured hemoglobine. During the further growth of the parasites, the pigment-granules increase in number, while the erythrocyte becomes paler and gradually begins to swell as a sign of incipient disintegration. When they average the size of a normal erythrocyte, the Plasmodia are "ripe" and prepare for multiplication; the food-vacuole disappears and the nucleus undergoes several successive divisions during which very tiny chromosomes are formed (Fig. 3). In the end, on an average sixteen small nuclei have arisen (Fig. 4) and the cellular body (which now usually floats free in the blood owing to complete dissolution of the erythrocyte) breaks up into a corresponding number of cells, the pigment-granules remaining in a small residual body (see centre of Fig. 5). The young daughter-organisms soon seek new erythrocytes into which they penetrate (Fig. 6) in order to go through the same development as their predecessors. The time they require for becoming mature is almost exactly forty-eight hours, and so you see that at the end of every such period an ever increasing number of young Plasmodia are ready to invade hitherto sound erythrocytes. They do so, in fact, and the body of the host reacts upon this by an attack of fever. So the regular recurrence of these attacks is in intimate causal connection with the life-history of the parasites that cause the disease.

What has here been described was for many years the only information we could obtain about this life-history: and yet there were some facts which left no possible doubt that it was only a part of the real history. Thus, it was not evident how the organisms first got access to the human system, in other words, how Man became infected with the disease. Further, the whole multiplication, so far as observed, took place asexually, by mere division of full-grown specimens, while from the general biological point of view it was a positive necessity that at one time or another a sexual reproduction should have taken place. This conclusion, based on purely theoretical reasons, was corroborated by the actual observation that, especially in the later stages of Malaria, Plasmodia were found in increasing numbers which differed more or less from the usual forms and by their whole conduct gave evidence that they were gametocytes. Under certain artificial conditions, they even developed into gametes, but all efforts to discover these under natural conditions, i.e. in the patients themselves, invariably failed. So the only alternative left was that the missing part of the life-history of the Malaria-parasites had to be looked for outside the human host.

As a result of the combined studies of a large number of investigators, among whom RONALD ROSS stands out first and foremost, we now know that it goes on **in the body of mosquitoes** of the particular genus *Anopheles*.

When these suck the blood of a patient they swallow along with it plenty of Plasmodia. While the asexual stages which happen to be among them perish, **the gametocytes continue their development**. These, as must here be stated, are recognisable from the beginning by the absence of a food-vacuole and the possession of a comparatively large amount of pigment. Any young microgametocytes are distinguished, in addition, by their large nucleus and their pale, feebly staining cytoplasm (Fig. 7 ♂), whereas young macrogametocytes have a small nucleus and a coarse, intensely staining cytoplasm (Fig. 7 ♀). These differential characters are retained by the gametocytes throughout their further development which chiefly consists in growth (see Figs. 8, 9). If after having reached full size they remain in the human system, they gradually perish (with an exception to which we will return later); if, on the contrary, they in due time reach the intestine of a mosquito, they actually **develop into gametes**. In the microgametocytes, the nucleus divides into (usually eight) fragments which come to the surface and collect some cytoplasm round them (Fig. 10 ♂). This soon after assumes the shape of a long lively beating flagellum (Fig. 11 ♂) and when detached from the residual body, with the nucleus at the its fore-end, completetely resembles a spermatozoon (see lowermost microgamete in Fig. 11 ♂). The macrogametocytes, on the other hand, by their large size and round shape (Fig. 10 ♀) already recalling the egg-cell, undergo a change which, as it recalls the maturation of the egg-cell, intensifies this resemblance. The nucleus divides into two portions, one of which remains in the body while the other is removed with a thin layer of cytoplasm round it (Fig. 11 ♀). By the formation of this "polar body" the macrogametocyte transforms into a macrogamete. This copulates with a microgamete while still in the intestine of the mosquito (Fig. 12), and the zygote then assumes a slender spindle-shape in which the male and female nuclei are still for a time recognisable as separated bodies (Fig. 13).

Here we have the sexual act, the existence of which appeared as a biological necessity from the beginning.

The **further development of the zygote** in principle corresponds to that we know from *Gregarina*, but also presents certain peculiarities of its own. It begins with the zygote making its way into the intestinal wall of the mosquito (Fig. 14; note that this figure and those up to No. 21 are about six to ten times less magnified than the preceding), which is composed of a single layer of epithelium-cells covered outwardly by an elastic membrane usually called the basement-membrane. Between this and the epithelium-cells the zygote settles (Fig. 15), surrounds itself by a thin **cyst**, and now begins to grow considerably (Figs. 16-20). In cross-sections through somewhat advanced cysts it appears as if during this growth the cytoplasm became broken up into an ever-increasing number of isolated portions (Fig. 19); it is, however, more probable that this division is only apparent and in reality due to a simple lengthening of the body which, being enclosed in the round cyst, as it becomes longer, must form ever more and denser coils, the cross-sections of which naturally take the shape of isolated pieces; this interpretation is indicated in Figures 17 and 18. In concomitance with the growth of the cytoplasm the nucleus multiplies by constantly repeated divisions which, in the end, may lead to the formation of more than a thousand small nuclei. The **sporozoites** subsequently develop round them in very much the same way as was described in *Gregarina* (Fig. 19). They also have a similar shape, so that, when mature, they are little, spindle-shaped bodies with rather pointed extremities and capable of slight movements (Fig. 21).

They do not, however, as in *Gregarina*, remain in the cysts, but the latter eventually rupture, thus allowing the sporozoites to swarm out into the abdominal cavity of the mosquito. Within this, they seek the salivary glands whence they are passively evacuated into a human being when he is stung by an infected mosquito; about the details of this process see later, page 211. The young parasites then enter the red blood-corpuscles and the life-cycle begins anew. In this way, the first of the above-mentioned points, concerning the manner in which Man becomes **first** infected with the disease, is also satisfactorily cleared up.

If we now **compare** this life-history of *Plasmodium* with that of *Gregarina* it is obvious that there is a considerable resemblance so far as the sexual reproduction goes. In both groups, there occur at a certain time gametocytes which transform into gametes. These copulate and the product of their union, the zygote, breaks up into sporozoites. We call this manner of development "**Sporogony**"[*]; such a sporogony is therefore present in both *Plasmodium* and *Gregarina*. In the latter, it is also the only form of development; for we saw that the sporozoites each again develop into a gametocyte which, by division, supplies new sexual individuals. This is not so in *Plasmodium*. Here the sporozoites, instead of at once becoming gametocytes, develop into forms which in the end also divide but thereby produce individuals which show no sexual distinctions and are capable of multiplying, without copulation, by mere multiple division. This manner of multiplication may be repeated several times, in other words, several such asexual generations may follow the sexual, the daughter-cells of each growing to full size and then dividing again. However, this reproduction does not go on beyond a certain limit. We already mentioned that after a number of attacks of fever these latter gradually cease; they do so because there is no more cause for them, i.e. no production of new young Plasmodia and no infection of fresh erythrocytes. We mentioned further that in the later stages of Malaria the gametocytes appear in increasing numbers among the axesual stages; this, from the biological point of view, is a sign that the Plasmodia gradually cease to be capable of multiplying asexually, but require sexual intercourse for "rejuvenescence" (compare here what has been said on p. 124). If this intercourse is prevented the organisms finally die out and the disease heals by itself. If, on the other hand, sexual union can be effectuated, fresh multiplying power is gained and a new series of asexual generations can be produced.

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[*] Greek, from σπόρος— see note *, p. 137, and γονέω (or γονεύω) —to breed, produce an offspring. The word means the entire development from beginning to end, whereas the form "sporulation" (see p. 137) only designates the particular process by which the spores are formed.

We therefore have, in *Plasmodium*, **two different methods of reproduction**, a sexual and an asexual; the former, you will remember, was called **Sporogony**; we differentiate the latter from it by the term "**Schizogony**" * and apply particular designations also for the various stages which occur in its course. The purpose of our doing so is the one already pointed out in the introductory remarks, viz. the necessity of a sharp distinction between the various stages for their exact comparison with the corresponding stages in the life-history of related organisms. I will not here burden you with all the terms actually in use, but some must be mentioned. The sporozoite, in *Gregarina*, develops into a gametocyte, i.e. a form which is already sexually differentiated, as it breaks up into male or female individuals; in *Plasmodium*, it is not sexually differentiated, as it develops into an organism which is going to divide into a number of asexual daughter-individuals; we allude to this difference by calling the growing *Plasmodium*-sporozoite a "**Schizont**"*. Its descendants, though in shape and general appearance resembling the sporozoites, yet have a very different origin inasmuch as they are not, like these, produced sexually, but asexually, by mere multiple division of the schizonts. This character of theirs is hinted at by their name "**Merozoites**"†. Each merozoite as it grows develops again into a schizont which divides into new merozoites. Gradually, however, some of these merozoites, instead of becoming again schizonts, become gametocytes, as was already described in detail.

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* Greek, from σχίζω—to split, divide, separate; the term refers to the production of new individuals by mere "splitting" of the original.

Within the life-cycle of *Plasmodium*, we thus have an **alternation between two different modes of reproduction.** There is a sexual reproduction, the Sporogony; but the individuals produced by it are asexual and for several times produce a new generation by mere division (Schizogony); their capability of doing so is, however, limited, for in the end a sexual reproduction must again take place lest the race shall be extinguished. It has already been mentioned that we call such a development "**Heterogony**" (or also "Heterogenesis"); we shall return to it more fully later (see pp. 196ff).

There remains now but one interesting point to be explained. On page 139 it was mentioned that very often new attacks of fever occur in patients who seem to have entirely recovered, and certainly have not been stung by an infected mosquito during the time of their apparent recovery. There is therefore no doubt that such a late attack—the "**Relapse**" (or "Recidive") as it is called—must be due to parasites derived from the first infection. For a long time there was considerable uncertainty as to the biological explanation of these relapses, i.e. as to the question how they could be brought into line with the life-history of the Plasmodia. Recent investigations, which we owe especially to Fritz Schaudinn, have thrown light even on this point; we now know that the **relapses take their origin from certain macrogametocytes**. You will remember that in the successive attacks of fever gametocytes appear among the ordinary merozoites in increasing numbers, but that they never develop into gametes so long as they remain in Man (p. 141). The microgametocytes even perish after a relatively short time; the macrogametocytes, although capable of waiting very much longer, eventually also die, with the exception, however, of some which undergo a very peculiar change and thereby **re-transform into schizonts**, that is, re-gain the capability of multiplying by mere division. The respective changes are represented in Figs. 22–24. Their starting-point, as already mentioned, is the ordinary macrogametocyte (Fig. 10 ♀). Its nucleus first divides (Fig. 22); one of the products of this division is subsequently somewhat pushed aside and henceforth remains inactive, while the other part divides several times and thereby initiates a multiple division of the cell (Fig. 23). In the end, we again have about sixteen young merozoites and a residual body which, in this case, encloses the inactive part of the original nucleus (Fig. 24).

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* Meaning "a stage which is going to divide" (see σχίζω, note *, p. 145).

† Greek, from μέρος—see note *, p. 133.

The whole process is most remarkable by itself and becomes even more so by the resemblance it offers to the "maturation" of the macrogametocyte (Figs. 10 ♀–12 ♀), in which also a part of the actual nucleus is inactivated. This part, however, is obviously not the same in the two processes. The conditions we found in the Paramaecia (p. 130) strongly suggest that in the ordinary protozoan nucleus a sexual and a vegetative portion are combined. If we admit a similar composition of the nucleus in the case of *Plasmodium* there would be every probability that the nucleus in the macrogametocyte still possesses both portions, but rids itself of the vegetative, when it is preparing for the sexual act, while, when the sexual act, though required, cannot take place (as is the case in the human host) the macrogametocyte reactivates the vegetative portion by extruding the sexual. So the behaviour of the plasmodian macrogametocytes throws an interesting light on the conditions we found in *Paramaecium*, while at the same time it receives its explanation from these.

The merozoites derived from the retransformed macrogametocytes, for a time at any rate, have regained the faculty of reproducing themselves by division, and in doing so lead to a recrudescence of the disease. From the biological point of view, we may consider this behaviour of the macrogametocytes as a last endeavour on the part of the parasites to preserve their race. Since, in Man, they can multiply only asexually, and can do so only for a limited number of times, they must in the end all perish if they are not before transferred into a mosquito. By retransforming into schizonts the macrogametocytes delay the definitive extinction of the Plasmodia contained in a patient, and thereby give them a new chance of reaching a mosquito and there performing copulation before it is too late.

In conclusion, I will shortly **recapitulate** the chief facts we described in the preceding discussion. The life-history of *Plasmodium* affords an example of copulation in which the uniting individuals show marked sexual distinctions which recall those between egg and spermatozoon. The whole life-history is an instance of Heterogony, that is, of a development in which the generations of sexually differentiated individuals do not follow each other immediately, but are separated by one or more successive generations of sexless individuals. Another remarkable feature is that, during the whole development from one sexual phase to the next, a change of the surrounding is necessary inasmuch as the sexual forms can only live and multiply (by Sporogony) in the mosquito, while the asexual live and multiply (by Schizogony) in Man. The symptoms of disease observable in the patients are in intimate causal relationship with the multiplication of the parasites.

AUTOGAMY.

I cannot conclude the present chapter without saying a few words about a strangely modified form of copulation which has been discovered within recent years in certain Rhizopoda, and plays—or has played—a part also in the life-history of Amoeba. Divested of all incidental features it runs in this way. The nucleus of an individual divides into two halves which withdraw to opposite ends of the cytoplasm and there each undergo two further divisions of a distinctly mitotic type. Of the four descendants thus arising from each half-nucleus, three remain inactive and subsequently become absorbed by the cytoplasm, while the fourth fuses with the corresponding fourth of the other half-nucleus. There is thus an undoubted copulation of two nuclei, while the two previous divisions of each are very suggestive of a reduction of their chromatic matter; the strange fact, however, indicated by the name Autogamy*, is that the fusing nuclei are direct descendants of the same nucleus and the same cell. What the special biological significance of the phenomenon may be, and, above all, whether it represents the sole form of sexual process occurring in the respective organisms, are questions as yet undecided.

Allusion was made above that Autogamy also plays—or has played—a part in the life-history of Amoeba, which thus far we have discussed but incompletely; the missing part, as you will remember, concerning the sexual reproduction of the animal. This has chiefly been observed in those species which live—as parasites—in the bodies of Man and animals, and thus have a special importance from a medical point of view; there is, however, little doubt that similar phenomena also occur in the free-living forms. Among the parasitic Amoebae of Man, three species are of greater interest; two of these, viz. *Entamoeba tetragena* and *Entamoeba histolytica*, because of their being the causal agents of certain disturbances of health combined under the name of "Tropical Dysentery", the third, viz. *Entamoeba coli*, because of its being, though harmless, yet fairly common even in moderate climates. It is the life-history of this latter species which has been worked out most carefully, and yet we shall see presently that our knowledge of it is, not even at present, free from gaps and misinterpretations; the animals being so small and delicate, and requiring so subtle methods for their investigation, that even skilled observers may at times fall victims to errors.

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* Greek; from αὐτός—self, and γαμέω—see note *, p. 136.

Entamoeba coli lives in the initial part of the large intestine of Man and there reproduces itself asexually, partly by simple division (as described on p. 68f) and partly by multiple division (as described on p. 113). However, according to the latest researches made, both processes deviate somewhat from the form in which we thus far conceived them; the division of the nucleus, during the ordinary division into two, being, not exactly amitotic, but mitotic, though in a very primitive form, while the multiple division of the animals seems to be preceded, not by a multiple division of the nucleus, but by several consecutive mitotic divisions such as described in the first place on page 113; the stage drawn in Figure 5, Plate II, thus having another significance, which, however, I cannot explain here.

After a period of asexual reproduction (after one method or the other) it appears that, in *Entamoeba coli*, just as we saw in the *Plasmodia*, the need of a sexual process arises. The animals then encyst themselves and the cysts leave the human intestine along with faeces. There is little doubt that the encystation of the free-living forms, as described on page 70, has the same significance. In the encysted specimens, after some time, four, eight, or even more, small nuclei appear in place of the originally single nucleus; a multiple division of the cytoplasm follows, and the cysts thence onwards enclose young Amoebae, corresponding in number to the nuclei previously present (Figs. 7, 8, Pl. II). Under the protection of the resistant envelope they remain alive even if the surrounding medium dries up completely; so they may become mixed with dust or dirt, may be blown about by the wind, but will break forth from their cysts and begin their life-cycle anew when they happen to get back into favourable surroundings; that is, in the case of free-living forms, into water, or, in the case of parasitic forms, into the digestive tract of a suitable host.

According to the generally received view, the sexual process proper, in *Entamoeba coli*, has the form of the Autogamy above described; it takes place in the cysts, and the young individuals appearing in these later are derived from a zygote, thus corresponding to the sporozoites of *Plasmodium* and *Gregarina*. According to the latest publications on the subject, the supposed Autogamy is not actually demonstrable; the young Amoebae are mere products of a multiple division of the mother-Amoeba (p. 113), but proceed to copulation as soon as they become free after reintroduction of the cysts into the required surroundings (see above). They accordingly represent gametes, while the mother-individuals are gametocytes.

On considering the facts as they appear in the light of the new observations, one can hardly fail to find that they look more plausible than they did in the light of the older interpretation; where the truth actually lies, only further research can—and eventually will—show.

C.—Fertilisation.

According to what was said on page 125f, we may define this process as a kind of copulation in which the uniting cells are no longer independent organisms, but specialised elements formed in, and eventually evacuated from, the body of a multicellular organism, for the purpose of reproduction. The particular organs in which these cells take their origin are the "**Genital**" or "**Sexual**" **Organs**. For the sake of greater lucidity I will, in the following discussion, refer to the conditions as they prevail in animals, while the corresponding conditions prevailing in plants will be dealt with in a separate chapter later (pp. 367ff). Among the enormous multitude of multicellular animals the sexual organs of course show a very varying and more or less complicated structure, upon the details of which we cannot here enter; their essential parts are everywhere the so-called "**Genital Glands**", i.e. those parts in which the sexual cells are actually formed; these are, in the male, represented by the **Testes**, in the female by the **Ovaries**. The description of the manner in which spermatozoa and egg-cells (or "ova") are produced in the respective glands must be left to your Histology-lectures; the ultimate changes by which they attain maturity, and become ready for function, are described on pages 115–118.

In the general definition of fertilisation, it was stated that the cells uniting in the process are derived from different individuals. This is indeed the rule; but there are some very interesting exceptions. It is a familiar fact to you that among all the higher animals, including Man, we find what is biologically called "**Separate Sexes**"; that means, every species is represented by two varieties of individuals, one having male sexual organs and producing only spermatozoa, the other having female sexual organs and producing exclusively ova. These species, therefore, as another term is, are "**unisexual**", i.e. every individual represents one sex only, and any two sexual cells, when they unite, **must** come from different individuals—a male and a female. The exceptions above-mentioned are due to the fact that in certain animals **male and female organs** are no longer separated but **developed side by side in the same individual.** Such organisms are generally termed "**Hermaphrodites**" * and their distinctive character, to repeat, is that the individual specimen is not a male **or** a female, but is a male **and** a female.

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* Ἑρμαφρόδιτος, Greek, originally the name of a mythological figure, later a general designation for persons who, physically or mentally, combined female with male properties.

This hermaphroditism is the **rule** among whole Classes and Orders of lower organisms. Many of these, by their particular manner of reproduction, still uphold the principle pointed out above, viz. that fertilisation takes place between sexual cells derived from different individuals; for their fertilisation is so-called "**Cross-Fertilisation**", because effectuated in such a way that two individuals unite and each, by its spermatozoa, fertilises the eggs of the other. You already know a process in principle identical to this from *Paramaecium*; you will remember that, there, during conjugation, each individual, while it gives away half of its nuclear substance, in exchange receives the equivalent amount from the other; whereas in the several cases of copulation we have studied one individual only receives while the other gives. An example of such cross-fertilisation in multicellular animals is supplied by the earthworm. We shall see later (p. 473) that this is a hermaphrodite; when it associates itself with another individual for the purpose of reproduction each of the couple acts as a male by emptying its spermatozoa into the other, and acts as a female by receiving these from the other. Further examples of the same process are furnished by many Trematodes (see also p. 199). These worms, inhabiting, as parasites, various organs of Man and animals, for the greater part are hermaphrodites, and reproduce themselves by cross-fertilisation, as do the earthworms.

However, the peculiar conditions under which the parasites live, as a rule entail a great reduction of their mobility, and thus frequently render this mode of propagation impossible; we then see that cross-fertilisation is replaced by "**Self-Fertilisation**"; that is to to say, any individual, in the absence of another, may content itself with fertilising its egg-cells by its own spermatozoa. The eggs thus produced quite normally develop into new specimens; nevertheless, this self-fertilisation, to all appearance, is only a shift to make up for the difficulties of always at the proper time finding a suitable mate. These conditions are instructively exemplified by the Trematodes in which self-fertilisation is observable rather more frequently than true cross-fertilisation.

In the examples thus far mentioned, every individual possesses independent male and female organs; the spermatozoa being produced in one or several testicles, the egg-cells in one or several ovaries, found side by side in the same body. There are, however, certain other, very interesting hermaphrodites which only have **one** sexual gland in which both spermatozoa and egg-cells take their origin. A well-known example of this sort of hermaphroditism is afforded by the snails (Arabic جرج), various species of which, in this country, chiefly inhabit water. The "**Hermaphroditic Gland**" of these snails produces spermatozoa and egg-cells simultaneously; but the individuals, strange to say, propagate their race by cross-fertilisation, because the two kinds of sexual cells leave the hermaphroditic gland each by a separate way and can thus be separately transferred to the other individual. This is no longer the case in a few hermaphroditic representatives of the "Nematodes" *. While the great majority of these, like e.g. *Ascaris megalocephala* (pp. 115, 117), are ordinary unisexual animals and have either a testis, or an ovary, in the species alluded to, when they first become mature, the sexual gland produces spermatozoa and is therefore a testis. The spermatozoa, instead of being voided, are stored in some part of the genital organs, and then the function of the genital gland suddenly changes, inasmuch as it begins to produce ova, turning thereby into an ovary. The egg-cells, before leaving the body, are fertilised by the spermatozoa previously produced and develop into normal new organisms. The fact that, in these cases, the formation of the male sexual products precedes that of the female is the reason for our calling this form of hermaphroditism "**Protandric Hermaphroditism**"[*].

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* Greek, from νῆμα—see note *. p. 83; for further details see p. 205.

I cannot leave this subject without explicitly directing your attention to the fact that, particularly in the literature referring to Man and domestic animals, the term Hermaphrodite is used in quite a different sense. In all the cases above referred to, it designates the normal and regular presence, in one and the same individual, of normally develcped and normally functioning male and female organs; in the other case it does not. In explanation, I must first mention that the genital organs of Man (and the greater number of animals) when they are being formed in the developing embryo—in the stage of the "primordium"[†] as the technical term is—are for a certain time identical in both sexes. There is little doubt that the future sex is already determined even at that early stage; but we cannot recognise it by our means of observation and therefore call the genital primordia, so long as this is the case, "indifferent". Later, they become "differentiated", i.e. we actually see that some primordia begin to present features which are distinctive of the male sex, while others in the same way show that they are destined to develop into female organs; in Man, for instance, this takes place at about the end of the third month of development. In the normal course of events these different genital organs of the adults arisen from the common primordium of the embryo clearly show the characteristics of the respective sex. It may, however, happen that, owing to some accident the nature of which we cannot always recognise, the regular development of the genital primordium is disturbed just about the period when it is becoming differentiated. In such cases the genital organs, when developed, do not fully exhibit the attributes of one sex, but a mixture of the attributes of both. Considerable differences may occur with regard to the degree of this mixture; there are cases known (of Man and animals) where it was so complete that it was impossible to decide whether the individuals should be described as males or as females. They were of course quite incapable of propagating the race. In the majority of cases known, however, a close examination of the mixed organs showed that one sex was more or less preponderant, and that certain characters only were borrowed from the other. The reason why I have mentioned these details is that **such abnormally developed individuals are also called "hermaphrodites"**; you will, however, see without difficulty that in these latter cases the term designates exceptionally occurring individuals, incapable moreover, in most cases, of propagating their race, whereas, in the biological sense, the same term applies to a perfectly normal occurrence intimately connected with the regular reproduction. In many of these latter hermaphrodites, despite the presence of male and female organs in the same body, there is a pronounced tendency that the sexual cells which unite in fertilisation should be derived from different individuals, the specimens behaving, in this respect, just like unisexual species. What follows hereafter refers exclusively to these latter.

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[*] Greek, from πρῶτος—see note *, p. 46, and ἀνήρ, genit. ἀνδρός—man, male.

[†] Latin, from "primus"—the first (=πρῶτος in Greek), and "ordiri"—to commence, originate; therefore: "first commencement".

When mature eggs and spermatozoa of an animal are observed under the microscope under suitable conditions, it becomes evident that they are attracted to each other, or, more accurately speaking, the mobile spermatozoa are attracted by the immobile ova. We are not as yet sufficiently informed as to the nature of this attracting power; at the present time, we call it "**Sexual Affinity**". Its most remarkable feature is that it is not under all circumstances the same. The sexual cells derived from very closely related individuals (e.g. such as brother- and sister-organisms), as a rule exhibit little or no sexual affinity, i.e. they manifest little or no inclination to unite, even under otherwise favourable circumstances. This fact observed under the microscope in the sexual cells of quite a number of different organisms, is in full accord with what we observe with the naked eye in our own race and in our domestic animals. Sexual intercourse between nearly related individuals often remains without result, and if it does yield offspring, these are weak in body or in mind and often die at an early age. Farmers, stock-breeders, and directors of zoological gardens know that the descendants of an individual animal, when propagating among themselves, with rare exceptions yield a scanty progeny, and one which is neither strong nor sound.

We technically call a sexual reproduction between descendants of one and the same ancestor, or—what is the same—between "blood-relatives", "**Inbreeding**", and it is a well-known fact that the oftener it becomes repeated the more surely it leads to a degeneration of the individuals and, sooner or later, ends in a complete extinction of the race. We every now and then have an occasion to practically observe these destructive consequences of inbreeding in human families. Farmers and other people who make it their business to artificially breed animals, from time to time have to introduce "fresh blood" into their stock, that is, to procure animals of a different descent, reared under different conditions, and couple them with their own; for they know that, unless this is done, the quality of their animals is certain to suffer. When speaking of the life-history of *Amoeba*, *Vorticella*, and *Paramaecium*, I had to emphasise the fact that these unicellular animals, after a period of flourishing growth, in artificial cultures invariably die out. You now learn the biological explanation of this phenomenon; the individuals gradually arising from the successive divisions of one original are all "blood-relatives"; even if in the culture, when it was started, several such originals were present, their descendants, by one or two epidemics of conjugation (or copulation), will all become "blood-related", and this will lead to their final destruction if no "new blood" is introduced, i.e. if no foreign individuals are added to the culture. If we do add them, and do so in time, we can stop the degenerative process until, by repeated copulations between old and new individuals, the blood-relationship among their descendants has again become general. The consequences of inbreeding therefore manifest themselves alike in multicellular and unicellular animals, and consist in a more or less rapid degeneration of the race. However, as there is hardly any rule without exception in the complex organic world, so occasional exceptions have also become known to the present rule. They are very interesting in various respects but cannot be discussed in these elementary lectures. The phenomena above pointed out, and representing the rule, are in intimate causal connection with the fact from which we started, namely, that the sexual affinity is little or nil in close blood-relatives.

The same in general holds good for the sexual cells of animals which are only distantly related and belong to different species, different genera, or even different Classes and Phyla of the animal kingdom. Their sexual cells have no affinity to one another, and thus a union between two of them would not lead to a result even if the union itself were possible, which in most cases it is not for purely mechanical reasons. If therefore, in an old story-book, or in a modern daily newspaper, you find wonderful things told about a prosperous union between a maiden and a fish, or between a rabbit and a duck, or what other similar combination may be imagined by some fanciful mind, you will know what these " observations " are worth from the point of view of exact science.

Within the two extremes here mentioned, viz. very closely related and very distantly related individuals, the sexual affinity gradually increases and becomes greatest between specimens of the same natural species, but of different descent, i.e. individuals between which there is no " blood-relation ". There are several other factors which exercise an influence upon the intensity of the sexual affinity, but we cannot discuss them here. At any rate, this **sexual affinity**, wherever it is present, **causes the spermatozoa to move towards the ova and try to unite with them.**

Before proceeding further I must shortly touch upon a fact which is certainly known to every one of you by particular examples and will still occupy us in some more detail later. It is that the descendants produced by any pair of parents not only show the general shape and structure of the parents—the descendants of the human species, therefore, the human shape and structure—but that even small peculiarities present in one of the parents may reappear in the child. As, in one case, the respective peculiarity may be "inherited" from the father and, in another case, may be inherited from the mother, it follows that the characters of both father and mother are, or at least may be, transferred to the descendant. Since, further, the child originates from a fertilised egg-cell, i.e. from a combination of one ovum with one spermatozoon, it is a logical necessity that the peculiarities of the father must be transmitted to the child by means of that spermatozoon, while the peculiarities of the mother must be transmitted to the child by means of that ovum. The latter inference does not appear stringent in the case of Man, because it seems possible that the ovum while it is fed through the blood of the mother during its early development might along with the blood also imbibe peculiarities of the mother. The inference is borne out, on the other hand, with every desirable stringency in all those animals the eggs of which are evacuated as soon as mature; any maternal characters appearing in the individuals hatched from such eggs must have been transferred to them by the egg-cells. What we observe in our own race is observable throughout the animal kingdom; it is indeed quite a universal rule that **every organism, by means of its germinal cells, is able to pass its own peculiarities on to its descendants.** If you keep this rule in your minds, you will easily understand what follows.

The particular circumstances under which fertilisation takes place vary considerably in the various organisms. The simplest conditions are found among a large number of animals living in water. Here, the sexual products, when mature, are simply voided into the water in large quantities, where the eggs float and are sought by the spermatozoa. We find this manner of fertilisation which we may call "**External Fertilisation**" in a number of invertebrate animals and, among the Vertebrates, especially in Fish, Frogs, and Toads. Being so simple, it is obvious that it can be easily imitated artificially; we indeed avail ourselves of "**Artificial Fertilisation**" for various purposes, both scientific and practical. In the former respect, the procedure affords an excellent means for following the process under the microscope and varying the factors which play a part in it, in such a way as seems necessary for the solution of all the different and intricate problems which have cropped up, and may still crop up, in connection with the study of fertilisation. In the practical respect, artificial fertilisation is at present employed on a large scale for changing and improving the races of certain valuable fish, e.g. trout. In various countries there exist at present large establishments for "artificial fish-breeding". By gently stroking and squeezing the abdomen of fully mature male and female fishes it is easy to empty their genital products; and by uniting those of selected specimens it is possible to obtain an offspring which, in one respect or another, is superior to the ordinary race, because it may combine, in one and the same individual, some valuable peculiarity which is exhibited by the father with another valuable quality present in the mother. In a good number of cases this result is practically obtained; in others, it may be the contrary; for, as the good qualities can be passed on to the descendants, so may be the bad, and examples are not wanting, from the human race as well as from animals, to show that the progeny of unequal individuals exhibit a mixture of the bad qualities of both parents.

In all the higher animals (and a number of lower) the egg-cells are fertilised while still within the genital organs of the mother-individual; we may term this variety "**Internal Fertilisation**". In these cases, the males must transfer the spermatozoa into the females, a procedure which in the various animal types is accomplished in very various ways. The greater majority, in both sexes, possess particular organs for the purpose —the males for transferring the spermatozoa, the females for receiving them—which are called "**Copulatory Organs**", or, as they are for the greater part external —at variance from the genital glands which are internal—are also called "external genital organs". They are of course not necessary to, and therefore practically absent in, the animals mentioned above in which fertilisation is external.

You might ask how, in these latter animals, it is possible to distinguish the sexes without opening the bodies. In a number of species, the two sexes are indeed outwardly alike, and we have no means of distinguishing them at sight; in by far the greater majority, however, the individuals have certain external peculiarities which, though bearing on the sexual functions, yet do so only indirectly and are thence termed "**Secondary Sexual Characters**", in contradistinction to the "primary" sexual characters which are afforded by the sexual organs proper.

We already know that such distinctions exist in certain **Protozoa**, but are absent in others. Thus, in *Paramaecium*, the conjugating individuals are (usually) alike, and even the nuclei that are exchanged do not show any noticeable difference. The same is the case in the gametocytes of *Gregarina*; in those of *Plasmodium*, on the contrary, we find differences involving both protoplasm and the nucleus. They (apparently!) have nothing to do with the sexual process itself, and therefore must be classed among the "secondary" sexual characters. Speaking of the gametes, I said that these are still difficult to differentiate in certain forms of *Gregarina*, because of their great likeness, while in others they show those distinctions described on page 135 and figured in Figures 9 and 10, Plate VIII. Opinions may differ as to whether these differences, along with those still more pronounced between both the gametes of *Plasmodium* and the sexual cells of the higher organisms, are just secondary sexual characters. However, one thing is certain, namely, that the distinctions in question, though not essential for fertilisation (because, as we have seen, they may be absent) yet so greatly facilitate the union of the sexual cells that in fact they do come very near the primary sexual characters. Anyhow, the differences between male and female sexual cells are outwardly recognisable sexual distinctions and as such in a certain sense foreshadow the "secondary sexual characters" of the

Metazoa.—We shall see presently that in these some of the characters under consideration are of practically the same nature as those of the single cells, though of course more complex and of a more varied description in concomitance with the more complicated structure of the multicellular body. Without entering upon great details I will here enumerate some of the more conspicuous. Among the Invertebrates and the cold-blooded Vertebrates, the males are usually smaller than the females which, as a rule, produce numerous eggs at one time and therefore present a larger size and plumper shape. This, again, more or less reduces their motility; we know many examples where the females are very sluggish, or positively sessile, while the males roam about. In the warm-blooded animals, on the contrary, the males possess a larger and more powerful body, for it is a habit with many of them to fight with their competitors for the possession of a female. In many Invertebrates, the males, at variance from the females, are equipped with very highly developed sense-organs, and by their presence are outwardly distinguishable. The fact is in intimate connection with the differences in motility just pointed out, for by the help of the sense-organs the males are able to find the other sex. This refers especially to the organs of smell, the sense which probably is the highest-developed of all others in the lower animals. From actual observations we know, for instance, that the males of certain notoriously rare moths must smell their females at a distance of kilometres. Further, throughout the animal kingdom the males may possess adornments or capacities evidently destined to catch the senses of the females and thus make the latter inclined to the males. Among the adornments which appeal to the sight there are, first, beautiful colours; they are especially characteristic of the males in the Insects (e.g. beetles, butterflies, etc.) and the Birds; remember in this connection the differences in the colours of cock and hen, pea-cock and pea-hen, and numerous other birds. Besides the colours, there may be particular structures, chiefly on the heads of the males, such as the horns of the stags, the mane and beard of the lion and allied forms, and the feathers and combs on the heads of various birds, etc., etc. To please the auditory sense of their females, many male animals possess a particular cry which, though it is not always pleasant to the ear of Man as, e.g. the nocturnal caterwauling of a tom-cat, yet must sound agreeable to the ear of the respective females. In many birds this love-call is developed into a most beautiful song. Many, even educated people, do not know that it is only the cock-birds that sing, nor do they know that these —at least in birds living in their natural freedom— sing only so long as they are on the lookout for, or in attendance upon, a bride, the gift of song thus being a secondary sexual character. In a number of animals, lastly, the males try to win the affection of the other sex by peculiar smells, for the production of which they have particular glands which are absent in the females. The best-known instance of such a smelling substance is musk, and it is significant that this substance is collected by Man in order that it may serve him for a similar purpose. The only difference is that, in the human race, it is chiefly the female sex which uses it, as it is the females who by wrapping themselves up in beautiful colours, by putting on adornments of the most varied description, by singing and scenting themselves, unwittingly perhaps and unintentionally, but none the less certainly endeavour to attract the attention of the male sex.

These examples may suffice to give you an idea of the nature and distribution of secondary sexual characters among the Metazoa. I may still mention that in those cases where they consist in outwardly visible structures they not infrequently change the general appearance of the males of a species to such an extent that these become fairly dissimilar to their females. The fact of the species then appearing, in some sense, under a " double shape " is the reason for our speaking in the respective cases of a "**Sexual Dimorphism**"*. The phenomenon is of frequent occurrence, though extraordinary variations exist with regard to the degree of the dissimilarity. There are animals (none, however, likely to be known to you) in which the males look so absolutely different from their females that one would never believe them to belong to the same species if their life-history did not evince the contrary. In many other cases the "duplicity in the shape" of the sexes is less marked (as, e.g. in the gametes of *Stylorhynchus* and *Plasmodium*, in many of the butterflies, moths, and birds above quoted, and so on), and in still others it becomes reduced to the ordinary primary and secondary sexual distinctions. Sexual dimorphism therefore, however strikingly it may be displayed by certain species, is not sharply separated from the usual condition that males and females of a species are in the main alike in appearance.

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* Greek, from δίς—twice, double, and μορφή. see note *, p. 189.

Returning now to fertilisation, we saw that, in certain animals, it takes place in the water outside the body and that, in others, it takes place in the genital organs of the female, after the spermatozoa have been transferred into these by means of the copulatory organs. The fertilised egg-cells, in the latter animals, may be removed from the body of the mother, or they may remain and develop in it. In the former case, they are, as a rule, previous to evacuation surrounded by a protecting envelope, the egg-shell, and are thereby transformed into what we call the **Egg.** There is therefore, in the strict biological language, a difference between "egg-cell" and "egg", the former meaning what it actually says, viz. the egg-cell, the latter designating this cell together with all the envelopes and other equipments it may possess when it is voided from the parent organism. It has already been mentioned that we call animals that evacuate, i.e. "lay" their eggs, "**oviparous**", while those which retain the egg-cells until they have developed into mature embryos are called "**viviparous**" (see p. 43, note *).

I may here mention that the artificial fertilisation spoken of above can be effectuated also in such oviparous and viviparous animals; it is only necessary to introduce spermatozoa into females at the time when these have mature egg-cells in their organs. It will perhaps interest you to hear, as a reminiscence out of the history of biological science, that the first experiments of this sort were made about 150 years ago by an Italian priest and famous naturalist, SPALLANZANI, for the purpose of solving the mystery which at that time still enveloped the origin of new individuals in Man and animals. Convinced that, of the male individual, nothing but the semen was essential in the process, he kept a female dog in strict captivity until she became ruttish and then injected into her genital organs a quantity of semen freshly obtained from a dog. Although she continued to be kept secluded she in due time brought forth several pups. It was determined by this experiment that neither the presence of a male individual nor the act of coition were essential for the production of the young, but exclusively the semen. By further experiments, SPALLANZANI also proved that the fluid of the semen is of no importance and that the small " animalcules " contained in it, i.e. the spermatozoa, are alone the real "fertilising" agent.

Having spoken of the artificial methods of fertilisation, I cannot entirely omit mentioning another procedure which at the present time is very often adopted for improving the races of such animals and plants as are of practical importance for the requirements of Man's daily life. The procedure I allude to is called " **Hybridisation** ". We said above that the sexual affinity, while it is greatest between the sexual cells of individuals of the same species, is little or practically nil between members of different species. Although this is the rule, there are yet some very interesting exceptions to it. They are, according to our present knowledge, subject to no definite law but occur at random, as it were, among different species, especially those belonging to the same natural genus, or to closely allied genera. In order to be rightly understood I will quote a few examples of such "closely related" animals, irrespective of their sexual affinity; there are: horse, donkey, zebra; dog, fox, wolf, jackal; cat, tiger, lion, leopard; goose and duck; crow and raven; frog and toad; salmon and trout, and others.

As I have said, we do not as yet know the reasons, but the fact remains that the sexual cells of certain nearly related animals show sexual affinity to each other and unite when they have the opportunity of so doing. The egg-cells fertilised in this way in almost all cases known commence to develop, but usually perish before the development is completed: the abnormal fertilisation is **not** able to satisfactorily replace the normal. Only in comparatively few cases does a descendant derived from different parent species reach its full size, and such specimens are then called "**Hybrids**"*. They are as a rule easily recognisable both as regards their nature and their parentage, because in their shape and structure they more or less clearly exhibit a mixture of the parental characters, as e.g. a child produced by one representative of the white race and one of the black is neither white nor black, but has an intermediary colour, and also in other respects (formation of skull, hair, etc.) combines characters of either race. Hybrids between various animals (and also plants) occasionally occur under natural conditions; unfortunately, none of the forms which here come into consideration is likely to be known to you and so it would be of no use to quote them as examples.

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* Greek, from ὕβρις—outrage, offence, shame.

The natural occurrence of such hybrids opened an outlook in a practical direction. If the sexual cells of certain animals unite when coming together in the natural course of events, it was logic to suppose that they would also unite if brought into contact on purpose. This is what is actually done at present in what we call "**Artificial Hybridisation**". The earlier attempts in this direction were undertaken with the view to possibly obtain a combination of qualities which otherwise were found isolated in different species or races. The results have been varying, as indeed they can in no case safely be foretold; however, in the course of time, certain artificially reared animal hybrids have gained a great practical value. Thus, you probably know that the mule is a hybrid between horse and donkey and as such combines the greater size and strength of the horse with the greater endurance and perseverance of the donkey. In certain parts of France, hare and rabbit are hybridised, for culinary purposes, on a large scale, and some particularly good varieties obtained in this way have retained their characters without noticeable changes through many generations of pure breeding. I may here add that on the ground of extensive comparative studies we now are, scientifically, fairly certain that some of our most important domestic animals, such as cattle, pig, dog, and others, are the descendants of similar hybrids which, in prehistoric times, were obtained, probably by accident during attempts at domestication, from wild animals, some of which are still in existence, while others have since then been extinguished.

Before entering upon a description of the actual process of fertilisation it is necessary to say a few words about the cells which play the chief part in it. They both present certain interesting variations in form and structure. The **spermatozoa**, though cells with nucleus and protoplasm, only in comparatively rare cases retain the typical aspect of a cell. One such case is given by *Ascaris megalocephala*, the development of the spermatozoa of which we described in detail on page 117ff. In the Class "Crustacea"—the scientific name for all crab- (or crayfish-) like animals—the spermatozoa present a very varying and unusual shape (see Fig. 1 e and f, Pl. X) and are almost immobile; other provisions (upon which we cannot here enter) being made to ensure their meeting the mature egg-cells. In by far the greater majority of animals, however, the spermatozoa have assumed the external attributes of mobility in the shape of a long flagellum usually called **tail**, the beating of which enables them to quickly travel through the fluid in which they are suspended. At their anterior end there is a minute thicker part, known as the **head**. Its shape shows many variations in the different Classes and Orders of animals; the extremes are an almost spherical (but more or less flattened) shape on the one hand, and a long, needle- or cork-screw-shape on the other; some of these forms are shown in Figure 1 a–d of Plate X. Between head and tail there lies a more or less sharply marked intermediary piece, the **middle-piece**; it varies considerably as to size and shape in the various spermatozoa, but seems to be constantly present. All these variously shaped structures originate from typical cells and the investigation of this development has shown that the tail is formed by the **cytoplasm** of the original cell, that the head almost entirely consists of **chromatin**, and that the middle-piece either is the substance of the **centrosome**, or at least contains this latter. Thus indeed, in preserved and stained spermatozoa, we find the head and middle-piece intensely coloured while the tail remains more or less uncoloured.

The mature egg-cells also show some interesting differences which, although they are in causal connection with their later development, may best be described and explained at this place. The egg-cells of most animals are so small that they are not visible to the naked eye. You know that each is destined to transform into a new organism and that, during the process, it gradually divides into the numerous cells which compose the various tissues, organs, and systems. If we now imagine that this transformation into the embryo did take place at the sole expense of the egg-cell, the later organism, when it is born, or hatched from the egg, would not be larger than this; that is, it would be exceedingly small. The mature human egg-cell, e.g., has an average diameter of 0·3 millimetre ; if we suppose that this egg-cell developed into an embryo without anything being added to it the child, at the time of its birth, would have an average size of 0·3 millimetre also. You see at once that there would be very little probability of successfully rearing such a child to full maturity, owing to the difficulties which would arise in handling it, in properly nourishing it, in protecting it from accident and disease, and so on. So it is in the very interest of every creature and the preservation of its race to produce an offspring of the largest possible size. For, the larger and stronger any young organism is at the beginning of its independent life, the better it is enabled in case of need to help itself by its own resources. We now see that the animals comply with this natural demand chiefly in two different ways.

The viviparous animals keep the fertilised egg-cells in their genital organs and during development constantly supply them with food, in such a way that the embryo, while it develops, also grows considerably. The oviparous animals cannot follow the same plan. Being, for reasons which we cannot here discuss, compelled to part with the egg-cells as soon as these are fertilised, they must, if a supply of food is necessary for the progeny, supply it to the eggs **before** these are laid. Many oviparous animals do this, and for the purpose prepare a kind of condensed food-material which we call "**Yolk**". Under the microscope, this appears in the shape of minute, round or ovoid, strongly refractive granules which in most cases have a yellowish tinge. The granules are deposited in the protoplasm of the egg-cells while these are still in the ovary of the mother. It is self-evident that the bulk of the whole cell must increase in proportion to the amount of yolk contained in it. The young egg-cell of a hen, for instance, is of about the same size as that of Man, but when it is detached from the ovary and ready to be fertilised, it has reached about 100 times its former diameter and 1,000,000 times its original bulk. This increase is almost exclusively due to the addition of the yolk-granules; they are so numerous that, seen from outside, the whole cell reflects their yellow colour; for what is usually called the "yellow" or the "yolk" of the egg is biologically the egg-cell. It is, in the case of the hen's egg, still enveloped by a layer of colourless albumen (the "white" of the hen's egg), which is an additional food-material given to the developing chicken by its mother, but is absent in the eggs of most other animals. As a consequence of the deposition of the numerous yolk-granules in the protoplasm, this latter becomes reduced to very fine lamellae enveloping, and separating, the individual granules from one another. If it were possible to fix an egg and then dissolve the yolk-granules without hurting the protoplasm surrounding them, this latter would appear in the shape of a fine foam; and vice-versa, if in a fine foam, of soap, for example, we were able to transform the air contained in the bubbles into a solid substance, we would get an enlarged picture of the egg-protoplasm impregnated with yolk.

The differences in the egg-cells, to which allusion was made on page 172, are determined by the **amount** and the **distribution of the yolk** within the cells. Speaking first of the yolk itself, I may mention that it does not seem to be everywhere quite the same; the granules in the various types of animals differing in their microscopic structure and in their shape and colour as well. The differences observable as to colour have led to the distinction of a " yellow " and a " white " yolk which latter, in former years, was also called " Deutoplasm " [*]; but the name has not found general acceptance. With reference to the amount and the distribution of the yolk, the egg-cells have been divided into three varieties; it should, however, be explicitly stated that these cannot be sharply separated, but gradually pass into one another.

In a small number of lower animals the egg-cells contain either no yolk at all, or merely an insignificant amount; these cells are distinguished as " **alecithal** [†] egg-cells ". The ova of Man (and Mammals in general) may perhaps best be classed with them, for, although their protoplasm is comparatively abundant, and in the preserved state appears as a strongly granular, crumbling mass similar to certain varieties of yolk, yet this mass does not seem to play the same part in the subsequent development of the egg as does the true yolk. Thus it appears justifiable to ascribe the mammalian egg-cell to the alecithal type.

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[*] From the Greek δεύτερος—see note *, p. 133: a "second form of protoplasm".

[†] Greek, from alpha privativum (see note *, p. 4,) and λέκιθος—the yolk of the egg.

In the greater number of those egg-cells which possess a moderate amount of yolk this in the main occupies a central position, being densest round the nucleus and diminished towards the periphery. This type of egg-cell is differentiated as "**centrolecithal**"* (Fig. 2, Pl. X). It is typically represented by the eggs of certain worms, of which you already know *Ascaris megalocephala*; less typically by some "Insects" (a Class of animals represented, among others, by flies, butterflies, bees, locusts, lice; see also p. 233, note †). The yolk, in the measure as it becomes more abundant and the concomitant enlargement of the egg-cell more pronounced, causes a disturbance of the original equilibrium of the cell. For, as it is noticeably heavier than the ordinary protoplasm, it sinks to the bottom, i.e., accumulates in the lower half of the cell, while the protoplasm, including the nucleus, becomes shifted towards the top. Whereas, therefore, in all fertilised alecithal and centrolecithal egg-cells the nucleus occupies an exactly central position, it is in the remaining eggs found nearer to one side. From this character, the respective cells have received the name "**telolecithal**" † egg-cells (Figs. 3 and 4, Pl. X).

As a consequence of the arrangement just described the telolecithal eggs, if left to themselves under conditions where they can freely move, for instance in a fluid, will place themselves in such a way that the pole containing the nucleus faces upwards, and the opposite pole containing the bulk of the yolk faces downwards. They therefore have what we term a "**Polar Differentiation**". It may here be remarked anticipatingly that during the subsequent development of the egg-cell those organs which we previously (p. 31) described as "animal" organs first originate at the upper pole, while the "vegetative" organs remain for a certain time localised at the lower (for further details see p. 427). For this reason it has become customary to call the upper pole of the egg also "**Animal**", the lower "**Vegetative**" **Pole.** The two poles, apart from their different position, in certain egg-cells are outwardly recognisable by their different colour; in the eggs of frogs and their relatives, e.g., this is intensely brown or black at the animal pole, but yellowish-white at the vegetative (see Fig. 5, Pl. X).

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* From λέκιθος—see preceding note, and κέντρον—see note *, p. 59.

† From λέκιθος and τέλος—end, termination.

Many variations occur with regard to the degree of this telolecital arrangement. In the egg-cells of certain Invertebrates (e.g. snails), the disturbance of the original condition is only slight, the nucleus still lying near the centre (compare the cell shown in Fig. 3, Pl. I). The alteration is greater in the eggs of frogs and toads (Fig. 3, Pl. X), but reaches its perfection in the eggs of a number of fishes and of all birds. Here (Fig. 4, Pl. X), the egg-cells are very large (think of the hen's egg) and the protoplasm free from yolk-spherules is reduced to a thin layer occupying the middle of the upper surface of the "yolk". It appears to the naked eye as a round whitish area, already known to the earlier observers as the "germinal disc", and often allows us to recognise, situated at about its middle, a small, slightly more opaque spot, the "germinal spot" of the earlier observers, which is the nucleus of the egg-cell (Fig. 4*N*). We can, by the way, in the hen's (or any bird's) egg, easily convince ourselves of the fact above mentioned that the animal pole always faces upwards. For, from whatever side we (carefully) open a hen's egg — in a raw condition, of course — it will invariably present the germinal disc on its upper surface.

These are the main differences observable in the animal egg-cells; we shall see later that they greatly influence the manner in which the egg-cell commences its development (pp. 409ff).

We now turn to the actual process of fertilisation, i.e. a description of the phenomena which accompany the union of spermatozoon and egg-cell. They have been more or less thoroughly investigated in various animals, but especially, of course, in such eggs as can be artificially fertilised and, moreover, contain a sufficiently small amount of yolk to allow of a recognition of the occurrences within. The standard example of the former description is supplied by the eggs of a number of "sea-urchins" (see p. 230). Here (see Figs. 6–8, Pl. X) the egg-cells are surrounded by an envelope of apparently mucous consistence, but otherwise have no proper membrane. When the spermatozoa approach one and begin to penetrate into its mucous coat (by the help of their vigorously beating tails) the egg-cell sends a conical prominence of its substance, the so-called "reception-hill" (Fig. 6), towards the nearest spermatozoon and meets it half-way. As soon as this contact is accomplished (Fig. 7) the egg-cell, apparently stimulated by the fact, contracts somewhat and a clear space appears between its mucous coat and its surface (Figs. 7, 8); the space seems to correspond to a firm membrane, for no more spermatozoa henceforth succeed in making their way through it; the membrane is known as the "vitelline * membrane". Thus the egg by itself provides that only **one** spermatozoon should be admitted for the purposes of fertilisation. I may here mention in anticipation that in certain of the large egg-cells described above several spermatozoa have been observed to penetrate into the ovum, and that we are also capable, by artificial means, of weakening an egg-cell to such an extent that several spermatozoa may succeed in entering it. The consequences of such abnormal fertilisations will be related somewhat later (p. 182).

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* From the Latin "vitellus"—yolk (therefore the equivalent to the Greek λέκιθος).

Subsequent to the meeting of the head of the spermatozoon with, and its entrance into, the "reception-hill" sent out by the egg-cell, this prominence is again withdrawn and the head now lies in the egg-cytoplasm (Fig. 8). As to the fate of the tail the statements of the observers who have studied the sea-urchins' eggs are not quite uniform. The tail stops its movements soon after the contact with the egg has been attained, and then disappears from view—according to some authors, owing to disintegration outside the egg, according to others, owing to eventual absorption into it. In the case of many other animals, there is, however, no doubt that the whole spermatozoa enter the egg-cells.

The head, in the sea-urchins, from the periphery of the egg-cell gradually draws nearer to the nucleus which occupies the centre. During this migration a radial arrangement of the cytoplasm, starting from the spermatozoon, comes ever more clearly into evidence and is eventually very apparent. It originates from the centrosome of the spermatozoon (Fig. 9d) which, as you will remember, is represented by, or contained in, the middle-piece and, closely as this is connected with the head, has entered the egg with it. At the moment of entrance, however, the centrosome lies **behind** the head (Fig. 9a), whereas later, when the radiating figure is formed, its centre, which is the centrosome, lies in front of the head, i.e. between it and the nucleus of the egg. The attention of observers had no sooner been attracted by this interesting difference than its reasons were discovered under the microscope. The head and middle-piece of the spermatozoon, as a matter of fact, after they have entered the egg, make a **rotation by 180 degrees**, so that the middle-piece which initially was in the rear now takes the lead (compare Fig. 9, a–d). We may conclude from this singular conduct that the chromatin (composing the head), guides the spermatozoon so long as it is free, but cedes its leading role to the centrosome (represented by, or at least contained in, the middle-piece) as soon as a suitable egg-cell is reached.

The phenomena which follow are not, perhaps, more clearly recognisable, but are certainly more easily intelligible in the eggs of *Ascaris megalocephala* ; so these may serve us as example for the continuation of our description (compare here Pl. VI). When speaking of the reduction-division of the egg-cell, it was stated (p. 115) that this division, though as a rule taking place before fertilisation, yet in certain organisms may coincide with, or even follow it. The eggs of *Ascaris* afford an example of the second alternative ; thus while we find them engaged in extruding the unnecessary parts of their chromatin on one side (above in the figures) we on the opposite side (below in the figures) find the spermatozoa entering, or entered, into them. Both processes, in *Ascaris megalocephala*, take place within the body of the parent worm, but can easily be studied in dissected and preserved specimens.

The entrance of the spermatozoon into the egg does not offer any particular features; it is, in this case, certain that the whole spermatozoon with nucleus and cytoplasm is absorbed by the egg-cell; for the cone of strongly refractive substance characteristic of the free spermatozoa is at first also seen in it and only disappears later, apparently owing to dissolution in the egg-protoplasm (Fig. 2). The same happens to the remaining body of the spermatozoon which, as it consists of cytoplasm, becomes mixed with that of the egg-cell, the male chromosomes appearing then to float freely in the latter (Figs. 4, 5). The male centrosome which up to that time was not distinctly recognisable now comes into evidence in front of the chromatin, just as we saw in the sea-urchins' eggs. There now follows a very characteristic and suggestive phenomenon. We know from the development of the spermatozoa in *Ascaris* that the chromatin of their nuclei is derived from two chromosomes which, in the mature spermatozoa, have become blended together into a single round body of apparently solid chromatin (compare p. 118 and Figs. V and VI). As such a round body the male chromatin enters the egg (Figs. 1, 2), but, within this, gradually reassumes the shape of two independent chromosomes (Figs. 3, 4). Thus, when the egg has terminated the reduction of its own chromatin by the extrusion of the second polar body, we have, within it, **two sets of chromosomes equal to one another in number, but one derived from the spermatozoon and the other derived from the egg-cell** (Fig. 5; in order to distinguish the two, only the latter are now drawn in full shade, the former in dots). **Since, further, egg-cell and spermatozoon have reduced their chromosomes to half the normal number, the original total is restored by their combination.**

All the chromosomes, thus far condensed into short thick rods, now gradually swell until they again exhibit the usual loop-shape, while simultaneously drawing nearer to the centre of the egg-cell. They finally all of them arrange themselves in a median plane and become divided longitudinally (Fig. 6); the phenomena are quite the same as those occurring in the ordinary mitotic division of the nucleus (Fig. 3, Pl. V). The two daughter-nuclei thus each receive one half of **every** chromosome; in other words, each daughter-nucleus contains exactly half of the male and half of the female chromatin. As the egg-cell, during its development into the embryo, goes on dividing mitotically you see that the paternal and maternal chromatin must become strictly equally distributed to all cells of the new organism. You also see that the original number of the chromosomes must be preserved during all these divisions; hence the fact mentioned on page 111 that this number is the same in all body-cells.

Something still remains to be said about the conduct of the **centrosomes** during the first division of the egg-cell. In the earlier stages, the male centrosome was to be seen in front of the male nucleus. While the latter moves towards the centre of the egg, the radiating figure starting from it increases both in clearness and extent, so that eventually its rays nearly reach the periphery of the cell. As to the female centrosome, this played its usual directing part in the two successive divisions of the nucleus which led to the formation of the polar bodies, and, while three-quarters of its substance were extruded with these, the fourth remained with the chromosomes of the ripened egg-cell. There is therefore no doubt that the latter must contain a centrosome. Certain earlier observations now tended to show that **both** the male and this female centrosome, while they moved towards each other with the chromosomes behind them, divided into two, that the two halves moved asunder in opposite directions, and finally each joined a half of the other centrosome to fuse with it into one. Two new centrosomes would have arisen in this way which, however, were no longer one male and one female, but each half-male and half-female. By taking the chromosomes between them they would have formed the poles of the first division-spindle (as visible in Fig. 6). The whole process, anticipatingly, seemed fairly logic and natural, especially because, by it, the substance of the male and female centrosomes would have been distributed between the descendants of the egg-cell as the substance of the chromosomes actually is. Unfortunately, the respective observations of the original author have not been confirmed by subsequent investigators, and hence are considered as erroneous. Thus, what we at present positively know is that only the male centrosome divides and that its two halves form the attraction-centres in the first division of the egg-cell (Fig. 6), while the female centrosome seems to be destroyed and dissolved.

To recapitulate now the most important facts brought to light by investigation of the fertilising process, they are these. In normal fertilisation, one egg-cell meets with one spermatozoon. As, previous to meeting, both have evacuated half the normal number of their chromosomes, this number is restored by the meeting. In the first division of the egg-cell (and all subsequent divisions), the chromosomes are halved longitudinally as in any ordinary mitotic division; each daughter-cell accordingly receives exactly equal portions of paternal and maternal chromatin.

The importance of these facts is very suggestively enhanced by the observations made about **abnormal** fertilisation. We mentioned above that in the larger eggs, richer in yolk (such as e.g. those of frogs and birds), several spermatozoa not infrequently succeed in entering one egg-cell, owing perhaps to a tardy formation of the vitelline membrane all round the large egg. So far as actual observations at present go, despite the entrance of several spermatozoa, **only one unites** with the nucleus of the egg, the others remaining inactive and becoming finally lost to view. Experiments made with the eggs of various species have further shown that artificially weakened (e.g. anæsthetised) egg-cells also admit several spermatozoa, but that, in this case, their presence **utterly upsets the normal developmental processes** and leads to an early death of the young organism. Details, interesting and instructive though they may be, cannot here be given. The fact itself, however, and the others previously mentioned, clearly show that the normal fertilising process consists in the union of one egg-cell with one spermatozoon.

It also clearly shows the **biological value of the chromatin.** We were previously led to the conclusion (p. 122) that, as it is most carefully handed over to the descendants of a cell, so it also determines the biological similarity of these descendants; but there remained the question whether it did so alone or in association with other parts of the cell. This question can now be satisfactorily decided on the ground of what we have learned of the sexual reproduction.

Common experience tells us that paternal characters appear in a descendant just as easily and as frequently as do maternal. Hence the logical inference that, whatever the transmitting agency may be, it must in the fertilised egg be present in equivalent male and female shares. This necessitates our excluding the cytoplasm as such an agency. Leaving aside the probably existing cases in which the cytoplasm of the spermatozoon does not enter the egg-cell (p. 178), and in which it cannot therefore transmit paternal characters, we see that the proportion of male and female cytoplasm is so extremely variable in the fertilised eggs of the different groups of the animal kingdom (compare for instance its relative amount in the *Gregarina*-gametes on the one hand and in the sea-urchin's egg and spermatozoon on the other) that it cannot possibly account for the evident equivalence of paternal and maternal characters in the descendants. One might think, further, of the centrosomes as bearers of characters; but we have seen above that according to recent observations the female centrosome disappears just during fertilisation, leaving the field to the male. If this can transmit characters we ought logically to expect a preponderance of the male characters in the progeny, which, however, is not apparent.

There thus remains the chromatin. Now we have previously seen that it is most carefully divided into equal halves in the ordinary mitotic division of the cell; we have further seen that egg and spermatozoon (and most probably the Protozoa as well), before they proceed to union, evacuate half of their chromatic matter, that is, just that amount which they are going to again receive from their partner. In the descendant, therefore, the chromatin alone of all constituent parts of the cell is present in equivalent portions. We have seen, finally, that in the later divisions of the fertilised egg-cell the male and female chromosomes are arranged in such a way (Fig. 6, Pl. VI) that each new cell, whether it arises through the second or through the hundredth division, receives an equal share of both the paternal and maternal chromosomes. All these facts, if taken as a whole, leave no possible doubt that we must consider the **chromatin** as **the "Carrier of Inheritance"**, and the chromatin alone. The fact that it thus determines and, while being handed down from generation to generation, maintains the "properties" of every kind of organism is the reason for our calling the chromatin also "**Idioplasm**" *.

* From the Greek ἴδιος—being one's own; proper, peculiar to one.

2.—ASEXUAL REPRODUCTION.

When speaking of the asexual reproduction of the Protozoa we defined this as a multiplication which can be effectuated by any individual without the interference of another. The same definition also holds good for the Metazoa, with the apparent exception of the hermaphrodites (p. 153). I say "apparent" exception; for, though it is true that a hermaphrodite can produce a progeny as a single individual it yet does so by self-fertilisation, that is, by a sexual act. With regard to details the asexual reproduction varies considerably among the multicellular organisms. Perhaps the most remarkable cases are those in which the methods of multiplication are still the same as in the Protozoa, namely **division** (simple and multiple) and **budding**. Examples of multicellular animals reproducing themselves asexually after these methods will be found on pages 416ff and 473, while the frequent occurrence of budding among plants will be discussed on pages 380ff.

A singular feature about division in Metazoa is that the whole bodies of the respective organisms with all the tissues composing them break up into two or more descendants, while certain organs which according to the direction of the division can only remain with one descendant are formed anew, or "**regenerated**", as many times as they are needed. We shall have to say some words about "Regeneration" later (see pp. 421ff); for the present, it may only be pointed out that it stands in most intimate relation to the asexual multiplication by division and budding (see here also Vorticella, p. 93, and *Paramaecium*, p. 127).

More frequently than by this method, multicellular organisms reproduce their race asexually by cells specially delegated for the purpose; that is, by means similar to those they use for sexual reproduction. A comparative study of the protozoan gametes showed that their " sexual distinctions " were in all likelihood not primitive, but owed their existence to the necessity that at least one of them had to be mobile (p. 131 ; that quite the same conditions also prevail among the plants will be seen on pages 249, 253, 376). As it was the microgamete which changed its shape in adaptation to this particular function there was no corresponding need for the macrogamete ; we may therefore consider the shape of this latter as mainly primitive. In continuance of this reasoning, we may expect that the cells produced by the multicellular organisms for asexual reproduction will have the average shape of egg-cells and arise in organs resembling the ovaries. This is in principle indeed true, though great differences occur in details. So far as the animals are concerned we know of cases in which the cells at issue arise simply from the body-wall, without any trace of particular sexual organs, and we know of other cases, united to the former by numerous intermediary stages, in which such organs are not only present, but so well developed that they differ only by very slight deviations from the normal female type. It is only natural that in these latter cases the entire organisms should more or less decidedly display the outward appearance of female individuals, and we then have the singular phenomenon of apparently normal and typical females producing an offspring without the assistance of males; that is, the phenomenon we already mentioned under the name "Parthenogenesis" (p. 114). We will now investigate it in a few special examples ; before that, however, it should expressly be stated that parthenogenesis is, biologically, not sharply separated, either from the sexual reproduction, or from the simpler forms of asexual reproduction by special propagative cells.

A.— Parthenogenesis.

The actual occurrence of this form of development was first established beyond doubt about 150 years ago, but at that time met with universal disbelief. To-day we not only know that the respective observations were absolutely true, we also know that parthenogenesis is widely spread among the lower organisms, especially animals, and is absent only in the higher, particularly the vertebrate animals, including Man.

With reference to its occurrence we may distinguish two categories (= sorts, classes) of cases. In the one category these represent exceptions to the rule, i.e. the respective organisms reproduce themselves sexually, but every now and then, among a set of unfertilised eggs, a smaller or larger percentage, instead of perishing, which is the rule, develop into new full-grown individuals. In these cases, there is therefore—so far at any rate as the practical result is concerned—no sharp distinction between the parthenogenetic and the ordinary sexual reproduction. We call the phenomenon "exceptional", or

"**Spontaneous**" **Parthenogenesis**; the best-known example of it is supplied by *Bombyx mori*, the **silk-moth** (فُرَاش دودة القز), the caterpillars of which produce the silk and are commonly called "silk-worms" (دودة القز), although, zoologically, they are anything but "worms". The general life-history of the silk-moth is this; it is the same, by the way, as that of the "cotton-moth" (*Prodenia litoralis*), which represents the parent form of the notorious "cotton-worm" of this country. The adult female lays eggs, between 300 and 500 in number; from them, there hatch organisms in shape and organisation totally different from the adults, for they present a worm-like appearance (whence the vulgar name) and feed on the leaves of the mulberry-tree (as the young of the cotton-moth feed on the leaves of the cotton-plant). After having reached a certain size without undergoing noticeable changes in shape they manufacture themselves the well-known "cocoon", an ovoid house, or case, which is made — "woven", as it were — of one continuous thread, about 1000 metres long, of "silk". This, originally, is the secretion of two powerful "spinning glands" situated on either side in the abdominal cavity and opening outward, closely side by side, beneath the mouth; their epithelium-cells, by the way, present very good examples of those ramified nuclei we mentioned on page 56 and see figured in Figure 6, Plate I. When coming out of the spinning glands in the shape of a fine double thread the secretion is still soft and sticky, so that the two threads at once adhere to each other and fuse into one which still reveals its originally double nature by two fine grooves running all along its length, one on the upper, the other on the lower surface; thus giving the cross-section of the whole thread a distinct biscuit-shape. In contact with the air the substance of the thread quickly hardens; owing to this property, the thread can, when fresh, be pasted to foreign objects and older, already hardened, parts of its own mass; this is the way in which the cocoon is "woven". By a suitable procedure we are able to again loosen the pasted connections and thereby uncoil the thread, which in this state represents the raw silk. It may here be mentioned in passing that, from the appearance above described the silk-thread is always recognisable as such under the microscope; a fact which is of practical importance in so far as silken tissues, owing to the comparatively high value of the material, are not infrequently adulterated by unscrupulous manufacturers (compare in this connection the structure of the cotton-fibre, p. 337, and that of the flax-fibre, p. 347).

Within the cocoon, the worm-like caterpillar contracts considerably and assumes an almost immobile shape known as "pupa", from which after a certain time a new moth emerges. It has developed from the caterpillar by a complete transformation of all the latter's organs, and the cocoon was made for the special purpose of protecting the organism during this transformation (the cotton-worm, for the same purpose, instead of making a cocoon, withdraws into the earth and there transforms into a pupa). I will here mention anticipatingly that we call such a development, during which one and the same individual more or less completely changes its shape and organisation, a development by "**Metamorphosis**" [*]. The young stages thus differing from the adults in external appearance, internal structure and manner of living, are designated by the general term "**Larva**"; the maggot therefore is the "larva" of the fly, and the tadpole (Arabic : أبو دنيبه) is the "larva" of the frog, just as the caterpillar is the "larva" of the moth (for more details see pp. 208ff).

Under normal circumstances the eggs of the silk-moth, like those of its natural relatives, must be fertilised in order to yield new caterpillars; but exceptionally, as already stated, parthenogenesis may occur on a smaller or larger scale. The fact, in this case, is probably due to long domestication. For, according to old reports, artificial breeding of silk-worms has been customary in China (the original country of the animal) for the last

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[*] Μεταμόρφωσις, Greek—transformation, change of shape; the term is derived from the word μορφή—shape, form; hence a certain branch of Biology, which chiefly studies the shape of the organisms and their various parts, is differentiated as "Morphology".

4000 years, the first eggs having been brought to Europe about the year 550 B.C. It appears that during these long years of development under constant human control the animal has in some measure lost its original natural properties, a conclusion which may also be drawn from various experiences made with other domesticated animals.

Normal Parthenogenesis.—In by far the greater number of cases known parthenogenesis is thoroughly regular and must be considered as a normal occurrence. An instance, not destitute of practical importance for a certain part of human society, is afforded by the **life-history of the bee** (*Apis mellifica*, نحلة). In order to make you understand where the significance of parthenogenesis comes in I must say some words about the bee's life in general. You perhaps know that the bees, like ants, white ants, and other insects, are examples of so-called "state-forming" or "social" insects; that is, animals which live together in communities of hundreds or thousands of individuals, the life and work of which are regulated by laws more strictly ordered and more faithfully observed than ever in civilised human states; the bee-community, as a matter of fact, affords an example of those ideal conditions to which allusion was made on page 27.

Originally building their settlements in hollow trees and similar protected places, the bees have for centuries back been reared by Man in "hives" for the purpose of obtaining their honey as a valuable addition to human food. They are particularly suitable for the purpose because, at variance from some of their relatives (e.g. humble-bees), they collect honey only from non-poisonous plants. For the purpose of perfecting the methods of cultivation the life-history and the habits of the bee have been carefully studied. You perhaps already know that inside every bee-hive, whether artificial or natural, there are a number of "combs" which may be compared to partition-walls placed vertical and parallel to each other, being on either side densely beset with regularly hexagonal, hollow prisms, the "cells".

If we examine such a bee-hive, say, towards the end of the winter, we will first be struck by the observation that, inside, there is a temperature decidedly higher than that of the surrounding. We here have a practical instance of the fact previously pointed out (see p. 9) that even humbler organisms, by their metabolism, produce a temperature of their own. This is not noticeable in the individual bee but in the hive, where thousands of individuals are living together and where the walls prevent radiation, the temperatures of the individuals are aggregated and thereby become perceptible. Among the combs, we will find one or several the cells of which are filled with honey; they represent the "food-store" for the community during the cold season. Other combs may show in their cells maggot-like creatures which are the "larvæ" of the bee. The full-grown individuals, with one exception, are all of the same kind, and are those which in the warm season we find busy outside the hive; they are the "**Workers**" and, if examined anatomically, prove to be females the sexual organs of which—both glands and copulatory parts—have remained rudimentary*. The exception mentioned is the "**Queen**"; she is the only one of her kind, does not usually leave the hive, and if examined anatomically proves to be a fully developed female with abundant eggs in her two ovaries.

Life in the community becomes more active with the commencement of spring and is regulated in such a way that the workers continually build new cells from the wax which they secrete from certain parts of the surface of their abdomen. Into each of the new cells the queen lays an egg; the young organism which after a few days hatches from it has a thick, worm-like shape without wings and legs, and thus is what we already described as a "larva" (see p. 189). It is, in its cell, fed by the workers with "bee-bread", i.e. a mixture of honey and "pollen"*, and grows rapidly. When it has reached its full size, i.e. when it nearly fills the cell in which it is lodged, the latter is closed by the workers with a waxen lid, under the protection of which the larva undergoes its metamorphosis. This, as in the case of the silk-moth (p. 189), consists in a "change of shape", which concerns the outward appearance as well as most of the inner organs, amongst these especially the digestive system (compare Figs. 5 and 6, Pl. XXIV, and, later on, p. 232). About three weeks after the egg was laid the former maggot emerges from the cell as a new worker which at once joins in the work performed by its sisters. In this way life goes on in the bee-hive; the number of workers is steadily increasing until, towards midsummer, a change occurs.

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* From the Latin "rudimentum"—the commencement, first try, first attempt; rudimentary organs therefore are such as have not developed up to their normal and regular configuration.

Among the new cells built by the workers we then notice groups of such which, though regularly hexagonal like the others, are yet distinctly larger, while at the edges of the combs we find about half a dozen still larger cells which, besides, are irregular in shape. All these new cells are supplied with eggs by the queen; the hatched larvæ are fed by the workers, quite special care being given to those in the largest cells, which are nourished not only abundantly but with a specially prepared food. The full-grown animals they give rise to are new queens, whereas from the larger hexagonal cells there emerge forms not up to that time present in the hive, the "**Drones**". These, if dissected, prove to be males.

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* The "dust" of flowers; what it is biologically will be explained in the chapter on the reproduction of the plants (p. 368).

When these new individuals are ready to make their appearance, there takes place what the bee-keepers call the "swarming" of the bees. The process may vary in particulars, but the important feature always is that the queen with a part of her people leaves her old home and starts a new community at some other suitable place—in a new hive when this is kept ready for her reception. In the old hive, meanwhile, the drones and new queens are coming out from their cells. The virgin-queen which appears the first, flying out of the hive, high in the air copulates with a drone and then returns, carrying with her the "sign of copulation", viz. a peculiar appendix to her copulatory organs, which was not present before and on close inspection reveals itself to be the bitten-off copulatory organ of a drone. She then remains in the hive and continues the work of her mother. Her first coition is also her last, and the spermatozoa she has received in the act must last her for her life (which is about five years). They are stored away in a particular spherical pouch, attached to the sexual organs and called "seminal receptacle", whence at any time they can be produced for the fertilisation of the eggs. The few queens which emerge from their cells after the first may follow the same course as she did; as, however, there is no room for them in the original hive, they are compelled to start new communities, which indeed they do if there are sufficient workers to go with them. In this way the multiplication of the hives is effectuated.

The drones with the fertilisation of the virgin-queens have accomplished the work incumbent upon them; although doing nothing but eat, they are tolerated by the workers, which have to provide their food, until towards the autumn this becomes scarce. As a sufficient amount must be reserved for the whole community during the winter, the undesirable and useless feeders are, one fine day, all killed by the workers, a procedure which to bee-keepers is known under the name of the "massacre of drones". After the disappearance of the drones the bee-community re-assumes the condition it presented at the beginning of our description.

Here you have the life and the work, as they normally go on in the bee-community. However, there may be disturbances and a very serious one is that the community may suffer from "**Drone-Breeding**", as the technical term is. It consists in the fact that **all** the eggs laid by the queen, from a certain time onward, **invariably develop into drones.** As we have seen that these eat but do not work, it is clear that any community, from the moment it becomes afflicted with drone-breeding, is doomed. So bee-keepers and scientists endeavoured to find out the biological reasons of the phenomenon, in order if possible to obviate it in the future. It was soon discovered that the fault lay with the queen. In certain cases examined, she was found alive but, on close inspection after dissection, her seminal receptacle proved to be totally empty of living spermatozoa. In other cases, she was found dead and, in her place, there was another queen of somewhat dissimilar appearance which, on dissection, showed but incompletely developed genital organs entirely destitute of spermatozoa. In cases of this latter description, it was discovered subsequently that after an accidental premature death of the normal queen the workers, anxious to repair the loss, begin to amply feed some of the young larvae of workers that may be present. You will remember that the workers are females with rudimentary sexual organs; comparing this fact with the other that the queens have fully developed ovaries, but are also very carefully nourished in the larval state (see above, p. 193), it is not difficult to conclude that the particular development of the sexual organs depends upon the amount and the quality of the food supplied to the respective larvae. The correctness of this conclusion is borne out by the circumstance that the workers, by abundantly feeding larvæ of their own variety, indeed succeed in rearing individuals which hold an intermediate position between true workers and true queens, inasmuch as they have more highly developed sexual organs and ovaries which even contain a smaller or larger number of normal egg-cells. The most decisive feature, however, is that these emergency-queens cannot fertilise their eggs because they never had intercourse with a drone. Thus, in all cases of drone-breeding carefully examined, the evidence obtained concordantly suggested that the incapability on the part of the queen to any longer fertilise her eggs was responsible for the exclusive production of drones.

Concomitant microscopical investigations of the eggs themselves—both those of workers and those of drones—fully corroborated the above conclusion, and it was thus established that the queen, by **fertilising** certain eggs, makes them develop into **workers** or new **queens**, by **not fertilising** them makes them develop into **drones.** This result, first arrived at about sixty years ago, has in recent years been keenly contested by some bee-keepers, but the apparent evidence they brought forward against the old views, when submitted to a proper test, proved to support rather than to disprove the old views.

Thus, parthenogenesis is quite a regular occurrence in the life-history of the bee, but, what is more interesting, it exists only in the case of the males, while fertilised eggs invariably develop into females.

B.—Heterogony.

In the introduction to the preceding chapter I said that parthenogenesis is widely spread, especially among the lower organisms. In the great majority of these, however, it occurs not alone, or, as in the bee, side by side with sexual reproduction, but more or less regularly alternates with it, so that the whole life-history of the respective organisms assumes the form known as heterogony or heterogenesis (pp. 125, 146). We at present know a fairly large number of varieties of this development, which are chiefly determined by the particular form exhibited by the asexual part of the reproduction. For this reason, modern Biology distinguishes different forms of heterogony under different names; as, however, the time at our disposal is short I cannot here enter into details. So let me only point out some of the more outstanding variations and illustrate these by pertinent examples.

The chief feature, as repeatedly emphasised, is the alternation in the modes of reproduction: the usual form being that several or even many asexual generations are intercalated between two consecutive sexual. We already know this from the Plasmodia in which the sexual reproduction is represented by the sporogony, the asexual by the schizogony. A similar alternation between sexual and asexual generations will appear in all the examples to be given hereafter. Another very generally observable peculiarity of heterogonic animals is that the asexual individuals differ in **shape** and internal **structure** from the sexual. In particulars, many gradations occur; they depend chiefly upon the special development of the organs which in the asexual individuals supply the propagative cells. We already mentioned certain extreme cases on page 186; observation practically shows that in some of these the sexless individuals still outwardly and inwardly resemble the sexual (this will be exemplified by the plant-lice; see these), while in others the two may diverge in structure and appearance to such an extent that the first observers unhesitatingly considered them as different species and even as members of different genera (see the example of the liver-flukes). A last character common to many (but not all) heterogonic animals consists in their living under **conditions** which more or less **differ** for the two kinds of individuals. An example in which these differences are comparatively slight will be afforded by the plant-lice; in *Strongyloides*, on the other hand, we shall meet with a very marked difference inasmuch as the sexual individuals are "free-living", while the asexual are parasites; in the life-history of the liver-flukes, finally, both kinds of individuals will be found to be parasites, but to nevertheless evince the difference under consideration by their inhabiting each a different host. You will remember that we already found such a "change of host" in the Plasmodia which, so long as they live in Man, exclusively multiply by schizogony, whereas sporogony is restricted to the mosquito as a host. Now let us proceed to our examples. The first, presented by the

Plant-lice (also called "Tree-lice" or "Green-Fly") is interesting in so far as it concerns the same animals which 150 years ago supplied the first proof of the existence of parthenogenesis. If during the warm season, in a garden or a field, you closely look at the younger, sappy parts of the plants growing about, you will not infrequently come across some which are densely beset with numbers of small creatures of green or blackish colour, with six thin legs and, occasionally, two pairs of delicate, transparent wings. They are commonly known under the above names, or, scientifically, as **Aphidae**, and are, as may be stated in passing, **parasites** on the plants, because by a fine needle-like proboscis, sunk into the tissue of the plant, they suck the nutritive fluid which circulates there and has been prepared by the plant for its own use (compare definition of "Parasites" on p. 134). If you examine any such plant-louse anatomically you will, without exception, find it to contain female sexual organs with egg-cells and embryos at different stages of development, but there is no trace of copulatory parts. The embryos, when mature, are born (these lice are therefore "viviparous"; see p. 43); they settle beside their mother and develop again into females, and so on until the end of the warm season. This is the way in which the Swiss investigator BONNET discovered, and proved, the existence of parthenogenesis. He strictly isolated a plant-louse and after some time saw it produce living young; one of these was newly isolated but in due time again produced an offspring, and so on for about a dozen times. No male individuals ever arose during the whole series of these generations, nor could any foreign individuals get access to the isolated insects: the latter had indubitably reproduced themselves many times without the interference of males. Under natural conditions, things go on as described until the cool season makes its influence felt. Then we see specimens appear between the others which noticeably differ from them, and slightly differ also among themselves. They are the male and female **sexual** individuals, with sexual glands and copulatory parts; the egg-cells produced by the females **require** fertilisation to enable them to develop. These true females, moreover, are not viviparous, but lay eggs which last through the unfavourable season and then hatch asexual individuals which begin the cycle anew.

Liver-Flukes.—In nearly all countries of the globe, cattle, sheep, and similar animals, in the bile-ducts of their livers, harbour more or less plentifully worms which, if present in small numbers, may not cause great harm, but if present abundantly bring about a gradual destruction of the liver, which ends in the premature death of the hosts. The worms are commonly called "liver-flukes" and scientifically belong to a genus *Fasciola* which, in its turn, is a member of the Class **Trematodes** *. In Europe, the genus is represented by the " European liver-fluke " (*Fasciola hepatica*), in this country, by the " African liver-fluke " (*Fasciola gigantea*). Of their structure I will here only mention that near the anterior end of the flattened leaf-like body they have two circular openings (whence the name Trematodes) and, inside, they possess complete male and female organs; they are therefore hermaphrodites. The egg-cells produced in the female organs are fertilised by the spermatozoa produced by the male; cross-fertilisation, though possible and certainly existing, has not yet actually been observed just in these liver-flukes, though it is not uncommon in related forms.

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* Greek, from τρῆμα—hole, opening.

The eggs*, after having been laid in the liver, are carried to the intestine along with the bile and are eventually evacuated with the fæces. Only those which accidentally get into water find the conditions necessary for their further development; if you observe the habits of the cattle about in the country you will see that there are plentiful occasions for the eggs to reach water. Arrived there, the egg-cell contained in the egg, in the course of a few days transforms into a mature embryo which subsequently escapes from the shell (compare Pl. XI). It little resembles its parent, but by a coat of actively moving cilia recalls an Infusorium (Fig. 1). Of its internal organisation I mention but a number of clear round cells, in every respect similar to egg-cells, which occupy the posterior extremity of the body-cavity; they are the **germinal cells** (*Gc*, Fig. 2) from which the progeny develops, but no other trace of genital organs is visible. This young free creature was formerly very generally also called an "embryo", though simple common-sense should have told observers that an organism which freely moves about can never rightly be termed an embryo; so the name "**Miracidium**"† has been invented for it. It is capable of living and swimming about in water for no longer than an average of two days; within this time, it must find a new shelter, and this it does in a species of small snail living in the same water. Having met with a suitable specimen it makes its way into it by perforating the skin, but at the same time losing its ciliar coat. The snail thus becomes the "host" of the miracidium, but as it is not the host of the adult worms, we differentiate it as the "**Intermediate Host**" from the other which is the "**Definitive Host**".

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* To render the following more easily intelligible the account here given is somewhat generalised!

† Μειρακίδιον, Greek—boy, lad.

In the snail, the miracidium tries to find the liver, where it comes to rest and develops further; miracidia which do not find the liver perish. The further development almost exclusively concerns the germinal cells. At first attached to the body-wall, they disengage themselves from it and divide; since, however, the daughter-cells of each remain united, every germinal cell gradually transforms into a small multicellular ball (*Gb*, Figs. 1,2), and eventually into a new organism floating freely in the body-cavity of the miracidium. The body proper of the latter does not take any part in this development; the continually increasing progeny merely distends it (Fig. 2), so that in the end it appears as an inanimated sac, or cyst, with a thin granular wall and containing inside a varying number of young organisms in various stages of their development (Fig. 3). The earlier observers, when they first saw these "cysts", did not know what to make of them and called them "**Sporocysts**"[*]; we have retained this name in the sense that it designates a stage in the development of the Trematodes.

The organisms taking their origin in the sporocysts have not always the same shape; in the sporocysts of the liver-flukes they are small cylindrical creatures with one opening at the anterior end and a short blunt prominence on either side near the posterior (Fig. 3). They thus differ considerably in shape from the miracidium as well as from the sexually developed worms. When first seen by earlier observers they were taken for independent animals and ascribed to a genus "**Redia**"[†]. This name also has been retained, not, however, as the name of an independent animal genus, as it was meant originally, but as a convenient designation for a stage in the development of the Trematode-worms. The most significant feature in the structure of the rediæ is that in their posterior extremity they again possess such germinal cells as we found in the miracidia (*Gc*, Fig. 4). Their presence suggests that the further development of the rediæ will, in principle, be the same as that of the miracidia, and so indeed it is. After having completed their internal organisation the rediæ leave the sporocyst by boring through its wall, thus invading the liver of the snail in ever increasing numbers. Their germinal cells develop as described (Fig. 4) and the final result is that the originally slender and active rediæ become transformed into plump, sluggish sacs enclosing a numerous progeny in all possible stages of development. The germs, as they grow, are gradually found to exhibit the characteristic peculiarities of rediae; so there is, this time, no change of shape. The "daughter-rediæ", after having become ripe and having left the body of the mother-rediæ by an opening existing for the purpose (*Op*, Fig. 5), develop like these and so several generations of rediæ may still follow, until the snail's liver practically swarms with them. The original sporocyst, meanwhile, has died and disappeared.

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[*] Greek, from σπόρος—see note *, p. 137, and κύστις—see note *, p. 70.

[†] Name derived from that of the famous old Italian naturalist FRANCESCO REDI.

Whereas, in the earlier generations, the progenies of the rediæ again develop into rediæ, they commence, in the later generations, to assume a different shape; in other words, the asexual reproduction is not unlimited but must eventually be replaced by a new sexual reproduction. We then see organisms arise (Fig. 5) which, in the anterior half of their flattened bodies show the primordia of the two openings present in the adult worms, and in other respects also resemble these latter, whereas, behind, they run out into a rather vigorous, mobile tail (Fig. 6). After the allusion just made to sexual reproduction you will anticipate that these new forms are destined to again become the sexually differentiated flukes; but when the same creatures were first seen about 100 years ago things were not so plain to the observers of those times as they are to us now. The resemblance between the young forms and the adult Trematodes then known was easily recognised, but their mutual connection was perfectly obscure; so the tailed creatures were considered as independent animals and collected into a genus "**Cercaria**"*. The name is still in use at present, but, like those quoted above, instead of a genus, designates a stage in the Trematodan development.

The cercariæ, when fully formed, leave the rediæ in which they took their origin and, boring their way through the tissues of the snail as best they can, finally escape from it into the water. Their vigorous tail enables them to swim about in it for a couple of hours or so, but eventually the tail is suddenly thrown off, while a granular substance—the secretion of numerous glands situated immediately below the skin—is poured out all round the body and quickly hardens into a cyst (Fig. 7). This **encystation** may take place either free in the water, the cysts then sinking to the bottom; or it may take place on the surface of some solid body, as, e.g. the surface of a small animal or a plant living in the water. The encysted cercariæ, to all appearance, are capable of remaining alive for a considerable time, but they do not develop any further unless, accidentally along with food or drink, they are brought back into the stomach of the definitive host. Here, the cyst is broken after having been softened by the acids of the stomach, and the young cercariæ, thus set free, pass by way of the intestine and bile-ducts into the liver where they grow to mature worms.

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* Derived from the Greek κέρκος—tail.

This, in its main features, is the life-history of the liver-flukes and a number of their relatives. In other Trematodes, so far as we at present know their life-history, this has become somewhat shortened by the suppression of the rediæ, the progeny of the sporocyst developing immediately into cercariæ. It appears that in these cases the sporocysts, in exchange, are much longer-lived; growing continually, they may reach a considerable length and, exceptionally, even a generation of daughter-sporocysts may be produced previous to the formation of cercariæ. These are variations in the development of the cercariæ; others occur in their subsequent conduct in so far as in many Trematodes they no longer settle on the surface of foreign bodies, but penetrate into various aquatic animals to encyst themselves there. They eventually reach their place of destination when the respective animals are devoured by the definitive hosts.

By the help of mosquito-larvæ, or other species with a similar development, encysted cercariæ may thus even be carried into the air and there be picked up by hosts which (as e.g. bats, وطواط) do not by themselves come into contact with water.

In this life-history of the liver-flukes, we have, to repeat this, an example of heterogony combined with a change of host; both the sexual and asexual generations being parasitic but living, the sexual generation in one host— the "definitive" host — the asexual generations in another — the "intermediate" host. I also draw your attention to the considerable differences in shape and organisation which exist between the sexual and the asexual individuals, in which latter there is, moreover, no trace of any special sexual organs; the germinal cells simply originating from a certain part of the body-wall.

Our last example is **Strongyloides stercoralis**, a member of the Class "Round worms", or **Nematodes** *, from the typical representatives of which it, however, differs in various respects, among which the particular form of its development ranks first. Note therefore that this development is **not** common to all Nematodes, just as the development of the liver-flukes is not common to all Trematodes. *Strongyloides stercoralis* (compare Pl. XII) is more or less common in the warm and moderate climates of the globe and inhabits the initial part of the small intestine of Man, where it wanders about boring its way within the superficial layers of the mucous membrane. Even the full-grown specimens are extremely delicate creatures, appearing to the naked eye as fine, short, cotton-like fibres; if examined under the microscope (Fig. 1) they are found to be **exclusively females**, the organs of which are destitute of copulatory parts and accordingly never present traces of spermatozoa. The eggs they contain commence to develop while still within the body of the parent individual; the embryos reach maturity and hatch from the egg-shells before the eggs are voided from the host along with the fæces; the offspring of these parthenogenetic females, in the stools of infected persons, thus appear as young free worms (Fig. 2).

These, especially in their outward appearance, deviate from their mothers so much that the first observers believed them to be an independent species and gave them a separate name. They feed on the fæcal matter, and in the course of a few days grow into **normally built males and females** which, thus, are not parasitic, and, moreover, in many structural details noticeably deviate from their parthenogenetic and parasitic mothers (Figs. 3 and 4). When mature, these males and females copulate, and from the eggs they produce there hatch larvæ almost identical to the corresponding stage of their parents, i.e. identical to the young worms which first appeared in the fæces (Fig. 2). They, however, retain this shape only for a day or two and then undergo a metamorphosis, from which they emerge (as so-called "filariform larvæ") in a shape which exhibits all the essential features of the parthenogenetic and parasitic stage (Fig. 5). These filariform larvæ are capable of remaining alive in the fæces or, after the decomposition of these, in the soil for many months, but they do not change any further unless brought back into Man, where they again assume the shape of females and reproduce themselves asexually by parthenogenesis.

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* From the Greek νῆμα—thread.

From what has thus far been said it might appear as if the life-history of *Strongyloides stercoralis* were composed of two regularly alternating sexual and asexual generations. This is, however, not the case. If the (often very numerous) larvæ appearing in the stools of an infected person are carefully examined, it is found that only a part develop into sexual individuals, while the rest behave as if they were descendants of the free-living sexual generation, i.e. develop immediately into new filariform larvæ (i.e. from Fig. 2 into Fig. 5). As these become again parthenogenetic individuals it is clear that, in these cases, two parthenogenetic generations follow one another. There is nothing to prevent us from assuming that even more may follow the first, and the whole life-history of *Strongyloides* thus assumes a course in all essential details identical to that offered, for instance, by the plant-lice. If, further, we remember the fact seen, among others, in the life-cycle of the Malaria-Plasmodia, that the early asexual generations entirely consist of new asexual individuals, while gametocytes (sexual individuals) appear in increasing numbers in the later generations, it becomes fairly probable that something similar will occur in *Strongyloides*. Only it is difficult to prove this experimentally, because the parthenogenetic stages live parasitically in Man and animals, where the individuals cannot be isolated and followed through their subsequent generations. Be that as it may, there is no doubt that in *Strongyloides* every two sexual are separated from each other by several parthenogenetic, i.e. asexual generations, and that the whole life-history thus is an example of heterogony. Apart from this, it presents the particularity pointed out on page 197, that one of the two forms under which the species appears is parasitic, the other is not; in other words, that the two sorts of generations here differ in their manner of life.

All the examples of heterogony which I have here given may still serve as proofs of the fact emphasised on page 124 that the asexual multiplication of an organism cannot go on for ever but must at some time or other be replaced by the sexual.

The biological significance and origin of heterogony are not as yet satisfactorily established; it is even probable that the various types alluded to on page 196, as they differ in details, so also require a somewhat different interpretation. One thing, however, is certain, namely, that heterogony enables the animals to produce an extraordinary number of descendants and thus to preserve their race even under very adverse conditions.

In order to understand this let us assume that one of the above liver-flukes lays 100,000 eggs (a figure which very likely is too low rather than too high); it will not matter much if 99,999 of these perish, if only one suceeds in finding a suitable snail and there develops further. For the countless cercariae it gives rise to through the many generations of rediae will amply make up for the 99,999 lost eggs; and when one of these cercariae eventually yields a new liver-fluke the race is preserved as there is a new full-grown individual in place of the old.

In this respect heterogony concurs with a form of development which otherwise has nothing to do with any special method of reproduction but only concerns the fate of the individual organism after the commencement of its independent life. I mean the metamorphosis across which we already came when discussing the silkworm and the bee (p. 189) without, however, being able to give it that attention which it deserves from a general biological point of view. So it may still find a somewhat more detailed description here.

3.—METAMORPHOSIS.

The development by metamorphosis, to again insist upon this point, has its essential character in the fact that an **organism in the earlier part of its existence possesses a structure, and lives under conditions, which more or less differ from those of the adult**, and that during its individual development it therefore has to undergo those external and internal **changes** to which the term metamorphosis refers. Let me also remind you that the common scientific designation for **all** the different youthful stages which may exist is "**larva**". Metamorphosis is spread chiefly among the Invertebrate animals, but is also found in many lower Vertebrates: let us here study an example of each, choosing from the Invertebrates, to begin with these, a group of animals which we use to combine under the popular denomination

Mosquitoes or "gnats" (ناموسة) (compare Pl. XIII). They are so common in this country that I think they are familiar to every one of you; I am, however, not so certain whether you also know where they come from: in other words, how they develop. Speaking first of the full-grown individuals, if you look at one with the naked eye or, better still, with a pocket-magnifying-glass, you will notice that its body is composed of three sharply separated "regions" (Figs. 1 and 2); namely, a small, round, anterior portion, the head, a fairly thick and stout median portion, the thorax, and a long cylindrical, posterior portion, the abdomen. While this latter is destitute of any external appendages, the thorax carries, on its dorsal aspect, a pair of transparent wings which, under the microscope, are seen to be more or less densely covered with fine scales, and, on its ventral side, three pairs of rather long and slender legs. On the head we find certain other organs, viz. a pair of large round eyes (seen below and on either side in Figs. 3–5) and two pairs of hair-like appendages, one of which, known by the name of "**Palpi**" and marked *p* in the figures, may be long (Figs. 3–5) or short (Fig. 4), while the other pair (*a* in Figs. 3, 5), called the "**Antennæ**", are always long and, as they carry on them sense-organs (auditory and olfactory), supply "secondary sexual characters" (see p. 165) of the mosquitoes. If you closely look at a number of specimens you will, in some of them, notice tiny feather- or tuft-like structures in front of the head (Fig. 3), which in other specimens are absent

(Fig. 4). The former individuals are the males, the antennæ of which, in connection with the more highly developed sense-organs (see p. 165), have assumed the feather-like appearance. As this latter is absent in the females (Figs. 4, 5), the two sexes may be recognised at once from their antennæ.

The most characteristic appendage of the head is the trunk or "**Proboscis**" *, a single, straight bristle directed forward, by which the mosquitoes suck the blood of Man and animals. This seemingly simple bristle (e.g. Fig. 4), if examined microscopically, exhibits a very complicated structure; representing, roughly speaking, a hollow tube slit open along its dorsal surface and containing, inside, several hair- or sword-like structures; some placed laterally and consequently present in pairs, others lying in the axis and being single. Figure 11 diagrammatically shows these conditions in a cross-section; you see, below, the thick wall of the outer tube and, in its cavity, two paired and two unpaired cross-sections of inner parts. Of the former, the large ones near the bottom correspond to two blades ending, at the tip of the proboscis, in a kind of saw; by moving them to and fro the mosquito is able to pierce a hole into the skin. The two unpaired sections visible in Figure 11 are both hollow, the respective cavities extending throughout the length of the parts. The fairly wide upper or dorsal canal (*i* in the Figure), inside the body, passes over into the alimentary canal and its outer opening is thus the mouth proper of the mosquito; the other, ventral canal (*s* in the Figure), rather narrow, inside the body communicates with the salivary glands and therefore is the excretory duct of these. A sagittal section through the proboscis thus exhibits conditions as approximately given in Figure 12.

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* Προβοσκίς—Greek, latinised "proboscis"—trunk (e.g. of the elephant).

When a mosquito stings a man the two axial parts of the proboscis are sunk into the hole made by the saw-like blades and a certain amount of saliva is poured into the wound through the canal *s*. It has an irritating action, the itching sensation caused by a mosquito-bite being mainly due to it; it probably also causes the blood to flow somewhat more freely towards the place of the sting and prevents its quick coagulation. The blood sucked up by the mosquito (by the aid of a complicated mechanism which I cannot here describe) goes through the wide, dorsal canal *i* into the alimentary system. If you duly consider the few details here mentioned of the structure of the proboscis and its manner of acting, you will more clearly understand what you learned on pages 142 and 144, namely, that any Plasmodia contained in the blood of Man must be transferred into the stomach of a mosquito when this sucks blood, and that any sporozoites contained in the saliva of a stinging mosquito must be transferred into the blood of the bitten person by the act of stinging. I must here add that in general it is **only the female** mosquitoes that **sting and suck blood,** whereas the males, usually unable to sting, content themselves with the nectars of flowers, the juices of fruits, etc.

All mosquitoes deposit their **eggs** on the surface of water; this latter is therefore indispensable for their development. The eggs are small, spindle-shaped, black bodies; they, in warm climates, after one to three days yield **larvæ** (Figs. 8, 9) which in no respect resemble their parents, being worm-like creatures composed of a number of "rings" or "segments" and bearing at their anterior, distinctly swollen end a small, sharply differentiated head, while the posterior end runs out into a number of appendages beset with tufts of long, stiff hairs; similar tufts are also found in the sides of the body, but there are no feet or other locomotory organs. These larvæ feed on small vegetable organisms contained in the water but, though living in this medium, they require air for their respiration. This they obtain by one or two tubes starting from the dorsal surface near the posterior extremity. If you observe a number of larvæ kept in a glass-jar, you will see that, so long as they are undisturbed, they all attach themselves to the surface of the water by their breathing-tubes, bringing the openings of these latter into communication with the atmosphere (+, Fig. 8). Give a gentle knock to the glass, or touch the surface of the water with some object, and they will all go to the bottom in quick wriggling movements, to return to the surface after a short time. Their want of air is thus obviously intense and you will now understand why one of the safest means for their destruction is the covering of any water containing mosquito-larvæ with certain oils. These, by spreading in a thin, continuous film all over the surface of the water, shut the larvæ off from the communication with the air and cause their death by suffocation.

After about a fortnight (the variations depending upon the temperature) these larvæ have reached their full size and prepare themselves for assuming the mosquito-shape. The structural transformations connected with this change of shape are very intense, for not only have certain organs to be formed which do not yet exist in the larva (as e.g. the wings, the legs, and, to a certain extent, the sexual organs), but also organs already in existence have to be moulded into more or less different shapes. This in particular refers to the digestive system which, in the larvae, is " adapted " to the taking up and digesting of solid (vegetable) material, while the full-grown mosquitoes feed on blood or, at least, liquid material and, for sucking up and digesting this, require an apparatus which is "adapted" to these new conditions. All the changes here referred to, quite especially those of the digestive organs, make it impossible for the larvæ to go on living and feeding as before. As an engine cannot work while a repair or a change in its mechanism is being carried out, so the systems and organs of an organism during a metamorphosis. We therefore see the larvæ assume a shape which holds an intermediary position between the larva and the full-grown insect: the shape of a "**Pupa**", as the technical term is (see also p. 189). This (Fig. 10) in the main has a U-form, the thick anterior half of which already allows one to recognise the future head and thorax with their respective appendages, while the posterior half remains slender and mobile as before. The pupa has no mouth, nor in fact does it take up food from outside, living at the expense of its adipose[*] tissue, a food-store prepared for the purpose during the larval life. Respiration, on the other hand, goes on as before; the breathing-tubes in the pupa have only changed their place, being now found shortly behind the head (+, Fig. 10). Within the pupa, most of the organs and tissues of the larva are broken up and dissolved; the material they consist of being used for building up the new tissues and organs of the full-grown mosquito. This process of destruction connected, in a higher or lesser degree, with every metamorphosis is called "**Histolysis**"[†]. When the metamorphosis is completed, the wall of the pupa bursts along the middle-line on the dorsal side and the organism, in its new shape, emerges from it, to henceforward lead a life totally different from its former existence.

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[*] From the Latin "adeps". genit. "adipis"—fat.

[†] Greek, from ἱστίον—see note *. p. 39, and λύω—to solve, dissolve.

The description here given specially refers to the metamorphosis of the mosquitoes; it should, however, be pointed out that, in its essential features, it is equally valid for silk-moth and bee, the metamorphosis of which was incidentally touched upon on pages 189 and 192, and is (partly) illustrated by Figures 5 and 6, Plate XXIV (for some further remarks on these figures see p. 232).

Up to about twenty or thirty years ago, the mosquitoes were of interest only to the Zoologist, while the rest of the scientific world merely saw in them annoying insects devoid of all practical importance. This view was thoroughly upset by the discovery that the mosquitoes are the agents by which the germs of quite a number of more or less serious diseases are transmitted to Man and animals. A flood of papers dealing with the anatomy, the biology, and the scientific classification of the mosquitoes was the consequence of this discovery, and the animals, at first hardly heeded, for a certain time stood in the foreground of scientific interest. The greater majority of the numerous species that became known by these studies belong to one of the two genera *Culex* and *Anopheles*, the latter, as already hinted (p. 141), mainly comprising the "**Malaria-mosquitoes**", i.e. those which alone are capable of rearing the sexual stages of the Plasmodia and thus transferring the disease from one man to another. As, in your future career, you may be called upon to tell an *Anopheles*-mosquito from a *Culex*, I will here shortly give their most conspicuous distinctions, omitting all those which can only be discovered by a more minute comparison. These distinctions concern the eggs, the larvæ, and the full-grown insects.

The **eggs** of *Culex* are always deposited in small, shallow, boat-shaped heaps, the axes of the individual eggs running about parallel to each other and perpendicular to the surface of the water (Fig. 6); the eggs of *Anopheles* are laid singly or in loose groups, lying with their long axes on the surface of the water (Fig. 7); both forms of eggs, as is evident from this description, floating on the medium. The **larvæ** of *Culex* have one rather long and wide breathing tube (+, Fig. 8); those of *Anopheles* have two so short that they hardly project above the level of the surrounding body-wall (+, Fig. 9). Moreover, the larvæ of *Culex*, when at rest, assume an almost perpendicular position, their heads hanging downwards (Fig. 8), while the *Anopheles*-larvæ, in the same state, lie horizontally immediately under the surface of the water (Fig. 9). The **full-grown insects**, finally, may most easily be distinguished by their peculiar attitude when settled. *Culex*, in this position (Fig. 1), to some extent imitates the shape of a humpback; the thick thorax being the part most raised, while the head with the proboscis, anteriorly, and the abdomen, posteriorly, are more or less inclined towards the underlying surface. The hind-legs are usually carried free in the air and raised above the abdomen. In a resting *Anopheles* (Fig. 2), the whole of the body, from the tip of the proboscis to the end of the abdomen, forms a straight line, always (and in some species very strongly) inclined towards the underlying surface. The long hind-legs are either not at all lifted from this, or, if they are, in the main remain below the abdomen.

In dead specimens the distinctions in the attitude here described become naturally more or less effaced, and certain species do not even show them clearly during life. In these cases the genus may safely be told by a microscopical examination of the head and a comparison of the appendages it carries.

These, as we have seen, are five in number, viz. the unpaired proboscis in the middle, and one antenna and one palpus on either side. In the males, these structures are all fairly long in both *Anopheles* and *Culex*, the antennæ presenting, in addition, the feathery appearance (Fig. 3). On account of these circumstances the heads of the male *Anopheles* and *Culex* look rather similar to one another; however, the distinction of the males is also of lesser practical importance, as they do not suck blood. In the females, on the other hand, the head carries, in addition to the proboscis and the (always) long and mainly hairlike antennæ, quite short palpi in *Culex* (*p*, Fig. 4), but long palpi in *Anopheles* (*p*, Fig. 5). If examined with the naked eye or a pocket-lens, the head of the female *Culex* thus seems to have only three appendages, while that of *Anopheles* has five, like the males in both genera. Moreover, the antennæ are, in the female *Culex*, always raised high above, and thus clearly separated from, the proboscis (Fig. 1), while in the female *Anopheles* proboscis, antennæ, and palpi lie closely against one another, thus yielding the appearance of only one fairly thick and stout bristle (Fig. 2).

The difference here enumerated in the structure of the heads, as they are equally well observable in living and dead specimens, are essential distinctive characters between *Anopheles* and *Culex*, while the particular attitude of the body previously mentioned practically suffices to differentiate the mosquitoes inhabiting this country.

Frogs and Toads.—A well-known instance of a development by metamorphosis among the Vertebrates is afforded by the frogs and toads (in Arabic both called ضفدع). We have already spoken of the eggs of these animals (p. 176). Before being evacuated by the females they are surrounded by a layer of albumen, which is at first quite thin but (by imbibing water, into which the eggs are laid) quickly swells up until it presents an appearance similar to that of the birds' egg's albumen. There is no external shell and the egg-cells are thus easily seen as small black balls within the transparent gelatinous mass. The creatures they develop into are the well-known "tadpoles" (Arabic: أبو ذنيبه), small black animals without legs, but carrying in their stead a long mobile tail, by the aid of which they swim about in the water. While the adult frogs and toads feed on animals (insects, worms, etc., which they have to search and catch) and respire by lungs, the tadpoles feed on vegetable debris and respire by gills after the fashion of fish. Their internal organisation is "adapted" to this manner of life; the intestine, as in all herbivorous * animals, is very long and, in the tadpoles, coiled up in a double, fairly regular spiral line; the circulatory system, intimately as it is connected with the gills, presents an arrangement in the main identical to that of fish (for more details see later p. 456f).

When the tadpoles, feeding and living as described, have reached a certain size, the four legs of the adults gradually commence to develop; the hind-legs being visible from the beginning as two small appendages on either side of the root of the tail, the fore-legs, hidden

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* From the Latin "vorare"—to devour, and "herba"—herb; collective term for all animals which feed on vegetable matter. The complementary term is "carnivorous" (from the Latin "caro", gen. "carnis"—meat) for the "meat-eating" animals. An intermediate position between the two is held by the "omnivorous" animals (Latin "omnis"—all), which normally consume a mixed diet. One of their natural representatives is Man; the doctrine of "Vegetarianism" is therefore not in accordance with anatomical and biological facts.

under the membrane which covers the gills, not coming into view until they break through it. This takes places in concomitance with the metamorphosis of the tadpole's organisation into that of the frog. It is, in this case, quite gradual. The lungs which have taken their origin as outgrowths of the wall of the œsophagus during the life in the water assume their definite shape and receive the blood-vessels necessary for their later function (details on p. 457). When they are ready for work the tadpoles leave the water; the gills, together with the blood-vessels leading to and from them, being now no longer necessary, become obliterated as does the membrane which hitherto covered the gills and the fore-legs.

There still remains the metamorphosis of the digestive apparatus. It is clear that this cannot do its work properly while the changes are being made; we therefore see that, just as in the case of the mosquito-pupa, the organism, deprived of the possibility of obtaining food from outside, draws from a food-store inside the body. This, for the young frog, is the tail which, with the abandonment of the life in the water, loses its necessity as a locomotory organ. Observation with the naked eye of a young frog, when it has left the water, indeed shows that the tail, at first present in full size besides the four legs, slowly shrinks in, and eventually becomes a mere short stump which soon after completely disappears. Close microscopical observations have shown that nothing of the substance of the tail is really lost to the organism; all the tissues being first broken up into small pieces and later dissolved into a fluid which serves as nutriment for the body, in the same way as previously did the fluid elaborated from the food by the stomach. When the tail is completely dissolved and absorbed, the metamorphosis of the digestive system of the herbivorous tadpole into that of the carnivorous frog is also accomplished: the tadpole has become a frog.

If we now ask why many animals develop in such a roundabout way instead of taking the straight course from the egg to their definitive shape it appears that the whole is a device in the interest of the preservation of the race, like those mentioned on page 172f. A comparison of the forms which develop by metamorphosis shows that many of them feed on materials which present certain difficulties in being obtained. Thus, to stick to the examples we have discussed, the nectars and the pollen consumed by bees occur only in small quantities in separate flowers; the blood required by the mosquitoes must in each case be procured by piercing the skin of a man or an animal; the running, jumping, or flying insects, which form the food of frogs and toads, must be searched and caught, and so on. If the young of the mosquitoes and frogs were confined to the same food as the adults from the moment they hatch from their eggs there is every probability that, owing to their small size, they would encounter considerable difficulties in obtaining it always and in sufficient quantity; in other words, many would starve and perish before reaching maturity. This loss would be all the more severe as the animals themselves are for the most part small and have many enemies which prey on them and destroy a large percentage even under favourable conditions. There can be no doubt that under such circumstances the preservation of the race demands an offspring as plentiful as possible on the one hand, and provisions for its satisfactory nutrition on the other.

With regard to this latter point we have seen on page 173 that many larger animals supply to their germs such an amount of food that these need not begin their independent life till they have reached a comparatively advanced size. Unfortunately, a similar procedure is not practicable in all those cases where an abundant progeny is demanded. The elaboration of the food-substance for the egg is undoubtedly a labour for the maternal organisms, and thus cannot exceed certain limits. It is I think safe to assume that, e.g. a female mosquito, as we observe it to-day, already gives to its progeny the maximum amount of food-material which it can economise; if therefore it became compelled to increase the size of its eggs for some stringent reason, this would only be feasible at the expense of their number which, as we have seen, cannot be reduced without increasing danger in another direction.

Here, now, according to our scientific views, metamorphosis comes in as an expedient for obviating both difficulties. The animals which develop by metamorphosis indeed produce eggs in as large a number as is possible, irrespective of their being only of small size; but the young which emerge from these small eggs, instead of nourishing themselves at once on the food of the adults, turn provisionally to materials which are obtainable both easily and in sufficient quantities (such as, e.g. the leaves of higher plants, or those small vegetable organisms which, especially in water, live together in immense numbers). It is not difficult to see that a change of this description practically removes a good deal of the adversities which the young organisms would otherwise have to fight against in their early life; but it is also clear that the same change necessitates an adaptation of the digestive apparatus to the changed food and, in addition, very often an adaptation of the whole body of the young to life in another medium as, e.g. water instead of air. So it happens that, while the moths feed on the nectars of flowers, and for this purpose have mouths converted into long sucking tubes, their larvae, the caterpillars, consume the leaves of plants and, in order to devour these, possess powerful gnawing jaws; and while the intestine of the frog shows the shortness characteristic of the carnivorous animals the intestine of the tadpole is long as is the rule amongst the herbivorous. (As to the different configuration of the digestive tract in bee-larva and full-grown bee compare Figs. 5 and 6, Pl. XXIV). All these particular structures of course lose their significance for the larvae when these have reached a size which enables them to adopt the normal food and mode of life of their parents; and so we see that at a certain period they are given up and exchanged for the normal structure of the respective species.

We already know these changes; their intensity varies in proportion to the grade of diversity which exists between the mode of life of the larvae and that of the adults. Though there are of course no sharp limits, we biologically speak of a "**Complete**" and an "**Incomplete**" **Metamorphosis** according to whether the difference in the larval and adult organisations, and the subsequent changes from the one to the other, are great or comparatively small. Thus, all the animals above discussed are examples of "complete metamorphosis", while, e.g. lice (قمل), cockroaches (صرصار), and others are examples of "incomplete metamorphosis", because, in their case, the young stages do not greatly differ from the old in feeding and mode of life and can therefore also assume the main external and internal structure of these latter from the beginning.

According to our scientific interpretation, then, metamorphosis is a means which enables animals to preserve their race by the production of a large number of germs without being obliged to give much food-material to the individual germ; the "larvae" earning by their own activity that amount which they did not obtain from their mother, but being for this purpose frequently compelled to assume an organisation and a mode of life of their own. The numerous secondary modifications which occur in metamorphosis cannot here be entered upon.

I must now make you acquainted with two subjects which, though of a more academic nature, yet have a great practical importance in Biology. I fear, at any rate, that you will not be able to fully grasp the meaning of various points, in part already mentioned, in part to be discussed later, so long as you are not familiar with, at least, the fundamental principles of the two subjects alluded to.

CHAPTER VII.

On the Scientific Classification and the Scientific Naming of Organisms.

I mentioned on a previous occasion that the number of independent " species " of animals known at the present time is very large, being probably above rather than below a million. Since ancient times high-minded men have been interested in these animals (and living organisms in general) from a purely scientific point of view, and have studied, with the means available at their respective epochs, the structure, development, and natural relationship, or the habits and mental faculties, of their fellow-creatures. Such observers are scarce among the ancient nations, but, among the Greeks, we have ARISTOTELES, sometimes called the " father of natural history ", among the Romans, we have the elder and younger PLINIUS, whose works, so far as they have escaped destruction, are even to-day interesting and important historical documents. In the centuries subsequent to the Greek and Roman periods, the interest in natural history was nil, but a flourishing epoch was initiated by the great discoveries of the fifteenth and sixteenth centuries, namely, the discovery of America by Cristopher COLUMBUS, 1492, the discovery of the sea-way to India by VASCO DE GAMA, 1498–1499, and the discovery of the magnifying glass by Zacharias JANSSEN, about 1590. While the seafarers returning from foreign countries brought with them an abundance of animals and plants unknown to the old world, the magnifying glass revealed the existence, in Europe herself, of a multitude of small organisms entirely unthought of before. The interest in natural history became greatly aroused by these discoveries, and there was a time when even princes indulged in studies with the microscope.

The extension of knowledge brought about by the new observations gradually taught that, lest the survey of the forms known should be lost, two things were absolutely necessary, namely, first, a certain regular arrangement of the different species, enabling the observer to survey their number and to easily find the place due to any particular species and, second, a definite naming of each independent species in such a way that no confusion with any other became possible. After some unsatisfactory attempts made by preceding writers. LINNÆUS (1735) succeeded in establishing a classification of the organisms which complied with both demands. Our knowledge has been steadily widening since the time of LINNÆUS ; especially has it been broadened and enlarged by the genius of Charles DARWIN. Thus, as a matter of course, various changes in the first proposals made by LINNÆUS have become necessary in the subsequent years, and will become necessary with the future progress of science. The general principles, however, laid down by LINNÆUS for both the scientific classification and the scientific naming of the organisms can be considered as definitive. It is these principles which I must try to explain to you. I refer, in the following discussion, to the animals in particular ; the classification and naming of the plants, being similar, do not, I think, require special explanation (see however pp. 316–326).

Turning first to the **scientific classification**, in order to make you understand its necessity, I previously alluded (p. 96) to the example of a big modern warehouse. Many of these establishments, at variance from the older, deal in articles of very heterogeneous descriptions, each article being kept in dozens or perhaps hundreds of specimens. Let us imagine a warehouse that has for sale, say, clothes, linen, shoes; articles for the table and the kitchen; necessaries for travelling; objects of art and other things, and now let us look at its internal arrangement. If you enter it, desirous of buying a suit of clothes, you cannot obtain this at any place, but you are shown into a particular department bearing, perhaps, a special board inscribed "Costumes for Gentlemen"; if, later, you desire to have some collars, you have to change into another department with, perhaps, a corresponding inscription, and if eventually you want to add a stick to your outfit, you are requested to enter a third place. Thus the whole establishment with the numerous articles it has for sale is divided into a number of departments, each dealing in articles of one general description. But the division is carried still farther. If you have bought a suit and want to add, say, an overcoat, you will find that you are requested to move again, or, at least, that the article is fetched from a place different from that at which you got the suit. Even the suits are not placed indiscriminately in the several cupboards or shelves that may exist, but are classified according to their size, to the quality of the stuff, etc. I will not add to this picture; if you keep your eyes open you will have no difficulty in verifying the details here mentioned and in addition many similar. I also think that, in this case, the practical advantage connected with the division and subdivision of the whole establishment—in other words, the purpose for which the divisions are made—are evident: the more consistently they are carried out the more easily the proprietor can survey what he has in stock, and the more quickly be can lay his hand upon any particular article that should be asked for. If you comprehend this, you will also comprehend the scientific classification of the animals (and of the organisms in general) which, in principle and practical execution, offers the same aspect.

The principle after which the animals are classified scientifically is their "**Natural Relationship**" which is **determined** by the greater or lesser **similarity in their internal organisation**. If you think logically you ought to demand that there should be, first of all, a character, or characters, common to all animals, and thus separating them as a whole from those organisms we call plants; such characters exist, in fact, but we must reserve their discussion until you have learned something more definite about the plants. Among themselves, the animals are classified according to their similarity in structure; it is a natural consequence of this procedure that there arise "divisions", "sections", or "departments" of different range and different content. I have already tried to show you, in connection with Amoeba (see p. 75f) and Vorticella (see p. 96f) that the "species" most nearly related to each other, i.e. sharing all the essential features of their organisation, are collected into "genera". It is self-evident that these genera, as a rule, each embrace few species only, because the number of species which show so far-reaching a structural similarity is limited; the number of the genera, however, is very large. They may display a more or less close relationship to each other and are accordingly collected into groups of higher value. Of these, you already know the "Orders"; between them and the genera it is often necessary to make intermediary divisions, called "Sub-families", "Families", etc.; but I think that I can here do without entering upon them in particular. The members of a natural Order, as you saw in the Amoebozoa, the Holotricha, and others, no longer share all the details of their organisation, but only agree in characters of a more general nature. This is the case in a still more pronounced degree in the "Classes", into which naturally related Orders are combined. You remember that the Amoebozoa and the Radiolaria (this is the Class with the internal silicious skeleton mentioned on p. 77) differed in structural details, but agreed in the particular form of movement, i.e. in a very general character. They thereby manifest themselves as members of the natural Class Rhizopoda. We found relations of the same nature between the Holotricha, Heterotricha, Hypotricha, etc., which, although their locomotory organs differed in distribution and arrangement, yet all had cilia as such organs. This fact is the reason why we combine all these Orders into the Class Ciliata. When speaking of conjugation, we learned to know the Class Sporozoa : unicellular animals united to each other, as indicated by their name, by the particular form of their development (see p. 132). You will, however, have become aware that the Gregarinæ and the Plasmodia, though agreeing in this general character, differed considerably in other respects. As a matter of fact, they are, in the scientific classification, representatives of different Orders of Sporozoa, namely, the Order Gregarinida, and the Order Hæmosporidia* respectively. You can find out their differential characters by a comparison of what has been said on pp. 132f, 139f, and 144ff. Rhipozoda, Ciliata, and Sporozoa, finally, agree in the very fundamental feature of consisting of one cell throughout their life ; this fact is taken into account by our combining them into the "Type" or "Phylum" Protozoa. You thus see that this Phylum embraces a very large community of species which differ in many particulars, but are all united to one another by the

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* From the Greek αἷμα—blood ; therefore Sporozoa which inhabit the blood, in particular the red blood-corpuscles.

most fundamental feature of their organisation*. The "Phylum" in this respect may be said to correspond to one of the "departments" of the warehouse, while the Classes, Orders, and so on, of the animals have their analogy, more or less clearly, in the subdivisions of the "departments". Further, as in the warehouse several different departments exist, each intrinsically independent from the others, so the animal kingdom, in addition to the Protozoa, contains other Phyla, the relations between which are comparatively loose, or are not as yet fully recognised.

Up to about thirty years ago we used to divide the whole animal kingdom into nine Phyla like that of the Protozoa; subsequently, however, various inadequacies of this division were found out and alterations were accordingly proposed and more or less generally accepted. Since these changes, in order to become intelligible to you, would require a knowledge on your part of many more structural details than I am able to discuss in these lectures, I will take the respective changes into account so far only as they are easily comprehensible. Even of the Phyla which exist I will select for discussion only those which are of a more general interest.

Since the Phylum Protozoa contains all unicellular animals, on the one hand, and none but unicellular, on the other, it must be considered as equivalent to the sum of the eight remaining Phyla which comprise the multicellular animals. You already know that we combine the latter under the common name **Metazoa**; the whole animal kingdom therefore first falls into the two large "sub-kingdoms" Protozoa (unicellular

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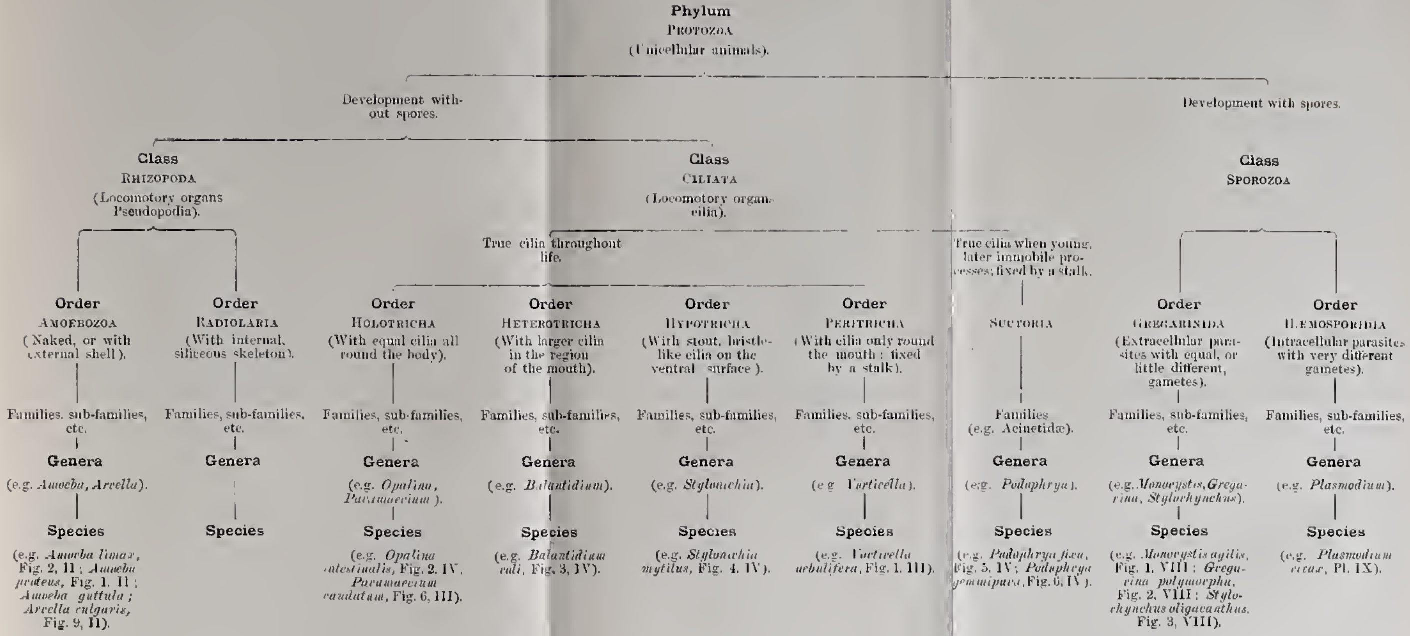
* For the sake of convenience, I give you, on the annexed page, a review of this classification in a synoptic form; it of course contains only those names, the bearers of which have been mentioned on the preceding pages, or figured on the plates.


Phylum
PROTOZOA
(Unicellular animals).
Development without spores.
Development with spores.
Class
RHIZOPODA
(Locomotory organs Pseudopodia).
Class
CILIATA
(Locomotory organs cilia).
Class
SPOROZOA
Order
AMOEBOZOA
(Naked, or with external shell).
Families, sub-families, etc.
Genera
(e.g. *Amoeba*, *Arcella*).
Species
(e.g. *Amoeba limax*, Fig. 2, II; *Amoeba proteus*, Fig. 1. II; *Amoeba guttula*; *Arcella vulgaris*, Fig. 9, II).
Order
RADIOLARIA
(With internal, siliceous skeleton).
Families, sub-families, etc.
Genera
Species
True cilia throughout life.
Order
HOLOTRICHA
(With equal cilia all round the body).
Families, sub-families, etc.
Genera
(e.g. *Opalina*, *Paramaecium*).
Species
(e.g. *Opalina intestinalis*, Fig. 2. IV. *Paramaecium caudatum*, Fig. 6, III).
Order
HETEROTRICHA
(With larger cilia in the region of the mouth).
Families, sub-families, etc.
Genera
(e.g. *Balantidium*).
Species
(e.g. *Balantidium coli*, Fig. 3, IV).
Order
HYPOTRICHA
(With stout, bristle-like cilia on the ventral surface).
Families, sub-families, etc.
Genera
(e.g. *Stylonichia*).
Species
(e.g. *Stylonichia mytilus*, Fig. 4. IV).
Order
PERITRICHA
(With cilia only round the mouth: fixed by a stalk).
Families, sub-families, etc.
Genera
(e.g. *Vorticella*).
Species
(e.g. *Vorticella nebulifera*, Fig. 1. III).
True cilia when young, later immobile processes; fixed by a stalk.
SUCTORIA
Families (e.g. Acinetidæ).
Genera
(e.g. *Podophrya*).
Species
(e.g. *Podophrya fixa*, Fig. 5. IV; *Podophrya gemmipara*, Fig. 6, IV).
Order
GREGARINIDA
(Extracellular parasites with equal, or little different, gametes).
Families, sub-families, etc.
Genera
(e.g. *Monocystis*, *Gregarina*, *Stylorhynchus*).
Species
(e.g. *Monocystis agilis*, Fig. 1, VIII; *Gregarina polymorpha*, Fig. 2, VIII; *Stylorhynchus oligacanthus*, Fig. 3, VIII).
Order
HÆMOSPORIDIA
(Intracellular parasites with very different gametes).
Families, sub-families, etc.
Genera
(e.g. *Plasmodium*).
Species
(e.g. *Plasmodium vivax*, Pl. IX).

animals) and Metazoa (multicellular animals). Among the latter, if we review them critically, there is again a very fundamental structural difference. You have begun your lessons in Dissecting, and from these you know that, when you open the human body, you find before you a cavity in which the various organs are more or less freely suspended. It is called the "abdominal cavity", or, in the language of comparative anatomy, the "**Coelom**"*. The lumen of the digestive tract, in particular, has no communication with it; for neither from the mouth nor from the anus can you reach the coelom without destroying the wall of the intestine. In other words, the digestive and abdominal cavities of the body are completely separated from one another. We find exactly similar conditions in the vast majority of the other Metazoa and with reference to this common character call them "**Coelomata**". In the remaining Metazoa, which do not possess such a coelom we find, on dissection, only one cavity which, for reasons which I cannot here discuss (see, however, the chapter on *Hydra*, especially p. 420f), must be considered as corresponding to both the abdominal and digestive cavities of the Coelomates. In the respective animals, as we scientifically express it, the two cavities are not yet separated, but are still united into one, a character indicated by the name "**Coelenterata**" †. These Coelenterates, in the classification of the animal kingdom, form a second "Type", or "Phylum", which is the lowest of the Metazoa.

When speaking, in a later chapter, of *Hydra*, which is a representative of this Phylum, we shall see that a very peculiar feature of the general structure of its body lies in the fact that various organs, in the same shape, are present several times and arranged round a longitudinal axis in such a way that every section passing through this axis would divide the whole body into two equal or symmetrical halves. In order to get an approximate idea of such a structure you may imagine an opened umbrella with knob-shaped handle. It is composed of equal parts lying opposite one another, and any section in whatever direction, supposing that it goes through the axis of the stick, would divide this umbrella into two equal halves. We call this general structure of the body, in the language of comparative Morphology *, a "**Radial Architecture**", and the several parts which compose the body "Antimeres" †. It is, apart from the Coelenterates, exhibited also by a number of Coelomates, which we classify as a separate third Phylum "**Echinodermata**" ‡. The "sea-urchins" (in Arabic: قنفد) frequently offered for consumption by street-pedlars in this town, the "star-fishes", and others, are representatives of this Phylum.

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* From the Greek κοιλός—hollow; κοίλωμα—cavity.

† To indicate that the κοίλωμα coincides with the ἔντερον—intestine.

In the remaining Metazoa, the "architecture" of the body is different. There are a comparatively small number in which no distinct parts such as composed the bodies of *Hydra* or the sea-urchins are recognisable. The organs are present singly, or at the most in pairs, in the latter case situated on either side; but apart from this, the body represents an undividable whole. We find such a structure, amongst others, in the Phylum "**Mollusca**" §, which comprises the mussels (أم الخلول), oysters, snails (جوجع), and similar creatures.

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* See note * on p. 189.

† Greek, from ἀντί—see note †, p. 37, and μέρος—see note *, p. 133; therefore "parts lying opposite each other".

‡ Greek, from ἐχῖνος—the hedgehog, and δέρμα—skin; the term refers to the spines with which the skin is armed.

§ From the Latin "mollis"—soft; the name refers to the fact that inside the hard shell, by which most of these animals are protected, there is a remarkably soft body proper.

In the vast majority of the Metazoa, however, certain organs, or whole groups of organs, are present several times as in *Hydra*, but they are not arranged round a common axis, i.e. opposite each other, but are placed one behind the other. You may conceive a fair idea of this architecture if you think of a passenger-railway-train. Although a unit of its own if taken as a whole, it yet consists of parts (the carriages) independent from one another, but in the main identical in structure, and only at the two ends, there are parts (the engine and the goods-van) which differ from the others owing to their different function. In comparative animal Morphology we call a structure like this a "**Metameric Architecture**" or "metameric segmentation", and the parts of which the body is composed "Metameres"*. While the peculiar location of the parts connected with the radial architecture makes it impossible to distinguish between a dorsal and a ventral aspect, or a right and a left side of the body, allowing only a distinction between an anterior and a posterior end (think of the umbrella), the metameric architecture does not prevent similar distinctions and the respective animals, showing (just as the railway-train) a right and a left side, a dorsal and a ventral aspect, have only one plane left by which their bodies may be divided into two equal or symmetrical halves. We in this case speak of a "bilateral† symmetry". Our own body affords an example of this; the "plane of symmetry" running half-way between the right and the left sides. The same plane, I may mention in passing, is also called the "sagittal plane", while the plane running from right to left (parallel to the forehead) is the "frontal" plane, and a third, running at right angles to both (i.e. crossing the longitudinal axis of the body at right angles) is the "transversal" plane.

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* Greek, from μετά—behind, after, and μέρος—see note*, p. 133; therefore "parts lying behind each other".

† Latin, from "bis"—twice, and "latus, lateris"—side.

In many Metazoa the metameric architecture combined with bilateral symmetry is fairly typically exhibited throughout life; an example of this is the earthworm which will occupy us in some detail later (see pp. 469 ff). Scientifically, we used to place the earthworms, together with a number of other worms which show no segmentation, but have a similar shape of the body, in the Phylum "Vermes". This is, however, about to be dissolved, because the forms it was made to comprise do not represent a community of true natural relatives.

Other Metazoa show a metameric structure more or less clearly during their embryonic, or larval, life, but lose it to a varying extent later; never, however, entirely. In order to understand this statement look at Figures 5 and 6, Plate XXIV, which represent dissections of a bee (Fig. 6) and a bee-larva (Fig. 5; compare here also p. 192), prepared by cutting away a part of the dorsal body-wall and thus exposing to view the inner organs. In the picture of the larva you perceive a body regularly composed of "segments" (the above-mentioned metameres), and, running through its whole length, a structure like a string of pearls. This is the nervous system, composed of "ganglia" (corresponding to "central stations" as explained on p. 32) and "commissures" (representing the connecting strands), in such a way that, with the exception of the last, each segment has its own ganglion. In this shape the nervous system of the bee-larva closely resembles that of the earthworm (see p. 472); while, however, in this latter, it retains its shape throughout life, it loses its regular arrangement by becoming "more concentrated" in the bee-larva, while this transforms into the full-grown bee. You see this in Figure 6, which additionally shows that the regular segmentation of the body in the larva has been replaced by an irregular segmentation, i.e. the formation of the three body-regions, head, thorax, and abdomen. These changes, however, and this is the important point, although in many Metazoa they may go much farther than in the bee, never go so far as to altogether efface the original metameric segmentation. Thus, in our own bodies, among others, this structure is still clearly exhibited by the vertebral column and the spinal chord, while the arterial system shows it during embryonic life, but loses it afterwards (compare here further p. 455).

These details may suffice to illustrate, and to explain, what I said above, viz. that many Metazoa show a metameric structure more or less clearly during their embryonic or larval life, but lose it to a varying extent later; never, however, entirely. This peculiarity is shown by two Phyla of the animal kingdom; one is the "**Arthropoda**"*, represented, among others, by crayfishes (Arabic : جمبرى) scorpions (Arabic : عقارب), spiders (Arabic : أبو بيض), and the insects (Arabic : حشرات†)

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* Greek, from ἄρθρον—limb, joint, and ποῦς—see note *, p. 63. The term therefore means to say that these animals have "feet composed of joints".

† In giving this word I find it necessary to expressly state that it does not quite correspond to the scientific term, being used for small Arthropoda in general rather than for the "Insects" in particular. These latter, as indicated by their names "Insecta" (from the Latin "insectum"—something cut into) or "Hexapoda" (from the Greek ἕξ—six and ποῦς—foot), are scientifically characterised by the general structure given above for the bee and on p. 209 for the mosquitoes; namely, a body "cut into", i.e. divided, into the three regions, head, thorax, and abdomen, and three pairs of feet, while the wings may be present (in two pairs, as in bees, butterflies, etc., or in one pair, as in flies), or may be absent (as in bugs, lice, etc.).

already mentioned on page 175. The other is the "**Vertebrata**", and represents the last and most highly developed Phylum of the whole animal kingdom. You perhaps know that its distinctive character lies in the possession of an "internal skeleton". As this is absent in all the preceding Phyla the members of these latter are often conveniently combined under the denomination "**Invertebrata**"; it will, however, be well to expressly state that this term (derived from earlier classifications) does not indicate a natural relationship of the respective forms, but is merely a collective term.

The most fundamental part of the skeleton is the vertebral column; you are familiar with its structure in Man, but it is not the same in all the other Vertebrates. We know a very peculiar kind of fish, the "lancet-fish" (*Amphioxus lanceolatus*) the entire skeleton of which is represented throughout life by a simple rod pointed at both ends and composed of a spongy tissue—the same, by the way, which forms the "notochord", i.e. the primordium of the vertebral column, in all higher Vertebrates. Strange to say, an identical rod has also been found in the larvæ of certain animals which, in the adult stage, are unmistakable Invertebrates. If we want to be consistent we cannot therefore any longer consider the presence of a notochord as distinctive of the Vertebrates. However, there is another character of these latter which sharply separates them from all Invertebrates, even those with the larval notochord; this is given in the relative position of certain organs within the body. From human anatomy you know that the nervous system lies near the dorsal surface, the abdominal cavity, with the circulatory system differentiated from it, near the ventral surface, and the vertebral column between the two. In all invertebrate animals, so far as they possess the same systems, their relative position is exactly inverted, the nervous system running along the ventral wall, the abdominal cavity, or circulatory system, near the dorsal. This characteristic arrangement is also found in the above-mentioned larvæ, and they thereby manifest themselves as true Invertebrates, the presence of the notochord notwithstanding.

As to the Vertebrates, I will here shortly mention that they are scientifically divided into five "Classes", namely, the **Fishes** (*Pisces*), the **Amphibians** (*Amphibia*), the **Reptiles** (*Reptilia*), the **Birds** (*Aves*), and the **Mammals** (*Mammalia*). I think I can here abstain from a special characterisation of the Fishes, Birds, and Mammals; besides, some details of their structure will be discussed in a subsequent chapter (XIV, 3, C). On the other hand, some explanatory remarks seem necessary concerning the Amphibians and the Reptiles, as many people do not know how to distinguish between them. The distinctive character of the Amphibians[*] is indicated in their name: they live in two media, namely, partly in water and partly on land; not, however, after the fashion of, e.g. a goose which according to its pleasure may walk about on land or paddle in water, but quite regularly in this way that the young stages live in water after the fashion of the fish, while their older stages abandon this medium and assume a life like that of the "terrestrial" or "land-animals". The only representatives of the Amphibians in this country are frogs and toads, about the metamorphosis of which we already spoke on pages 216ff; some further particulars about them will be found in chapter XIV, 3, C. The Reptiles never show a similar distinction between their young and their adult stages ; they are typical terrestrial animals even in the several cases in which they have re-adopted an aquatic life (as, e.g. the sea-turtles, ترسه). Representatives of the Reptiles living, or, at any rate, well-known, in this country, are the snakes (Arabic تعابين), the lizards (Arabic سحالى), the turtles (Arabic زحالف), and the crocodiles (Arabic تماسيح).

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[*] Greek; from ἀμφί—see note †, p. 118, and βιόω—see p. 2.

It now remains for me to say a few words about the scientific naming, or the **Scientific Nomenclature**, of the animals. I have already pointed out that owing to the enormous number of species known a clear and definitive system of naming them is indispensable in order to avoid confusion. It is clear that the vernacular names the animals have in the various living languages are not suitable for the purpose ; for, while nearly the whole mass of the smaller and smallest species have no vernacular names in any language, the large and practically important organisms, not only have names of their own in every independent idiom, but frequently even have several in one and the same. Under these circumstances, a general agreement upon one particular term as the scientific name of a certain organism would be impossible. So we refer to the dead languages for the purpose of establishing a scientific nomenclature, just as we did for the purpose of obtaining precise terms for the various biological processes, as was explained in the introductory remarks to the present lectures.

The most outstanding feature of this scientific nomenclature is that it is "**binomial**"*, i.e. each name is a combination of two independent designations. In order to render this principle clear to you I may recall our own names as an example. Each of us has a name by which he is personally called. But as this is not sufficient to distinguish him from other persons bearing the same name, we add to the personal the father's name which is the same for all the members of a family, while the personal names are different for each member. The full name of any individual thus becomes a combination of at least two names: the family-name and the personal name (or names). This system of combined names, though it does not altogether prevent a confusion between different persons, yet greatly reduces the possibility of its occurrence.

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* From the Latin "bis"—see note †, p. 231. and "nomen," genit. "nominis"—name.

In a similar manner, the full scientific name of an organism is composed of two designations: the first—the "**Generic Name**"—being the name of the genus and, as such, identical for all the members of that genus; the second—the "**Specific Name**"—being the particular name of the species and, as such, different for each member of the genus. In this way, the generic name to some extent corresponds to the father's name, the specific name to the personal name of the human individual. We have, in a former chapter, spoken of "Amoeba"; you will now understand that this word cannot be the full scientific name of a particular organism; it actually is only a generic name and, as such, refers to a group of several forms known as the "genus *Amoeba*". As a matter of fact, the general biological and structural details formerly described are common to all "Amoebæ", while differences exist with regard to details. Concerning these latter, I pointed out (p. 62f) that the number and shape of the pseudopodia differ, and that these differences (p. 76) are "specific" differences, i.e. distinctions of independent "species". In order to precisely designate one of these, we have to give it a "specific name" and add this to the generic name *Amoeba.* Thus, the quickly flowing form with usually one round and blunt pseudopodium (p. 62 and Fig. 2, Pl. II) is *Amoeba limax ;* the form with the numerous pointed pseudopodia (Fig. 1) is *Amoeba proteus ;* a third and rather peculiar form with a remarkably tough protoplasm and no individualised pseudopodia (not infrequent in this country) is *Amoeba guttula,* etc. What has here been exemplified by the genus *Amoeba* and its species is in all essential points valid also for *Vorticella, Paramœcium,* and the other genera, mentioned in the preceding discussions, or to be mentioned later. The full scientific names of the Protozoa illustrated on the plates are given in the synoptic review facing page 228.

I think you will have no difficulty in seeing that, by this system of naming the organisms, such a variety of different combinations can be formed as is necessary for the multitude of existing species, and, further, that the names thus obtained are far more precise than any others selected from living languages. In order to make any confusion, i.e. any coincidence in the names of different species, entirely impossible, care must only be taken that each generic name should be clearly distinguishable from all the others ; for, unless this rule is strictly adhered to, identical combinations are likely to arise. The condition is not quite easy to fulfil, considering that, on the one hand, the number of generic names already in existence may at present come fairly near to 100,000 and that, on the other, in former years, identical names were not infrequently given to two or even several different genera. Owing to an international agreement amongst Biologists, such double names are now to be abolished, and the consequence is the disappearance of a number of old and well-known combinations, a fact resented by many who have to deal with the bearers of the respective names.

In conclusion, I will mention that, owing to a recommendation in the agreement above referred to, we now use, when printing scientific papers, to give scientific names—and these alone—in *italics*. The principle is adopted in this book; you are thus enabled to at once infer, from the printed form of a name, whether it is meant in a strictly scientific or a more generalised sense.

You have by this time, I hope, gained a certain knowledge of the structure and the biology of the unicellular animals; we will now, for comparison, study some unicellular plants.

CHAPTER VIII.

On Life as Observable in the Lowest Representatives of the Vegetable Kingdom.

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1. Spirogyra* (Plate XIV).

If you pay attention to things about you you will frequently notice, floating in shallow pools of standing water, a green mass which recalls to mind tufts or skains of silk thread, but is in reality a plant. If you carefully isolate one of the threads from the mass you will find that it is very long, cylindrical, i.e. of almost *equal thickness* throughout, and entirely *unbranched*. A piece examined under the microscope exhibits further particulars. Even a low power suffices to show that the thread, though appearing continuous to the naked eye, is made up of a great number of *sections* fairly equal in length and separated from one another by straight partition-walls; only the two natural ends of each thread are regularly rounded. The green colour, instead of being uniformly distributed through the thread, is seen to be tied to certain definite structures sharply marked off from their colourless and more or less transparent surrounding. The structures themselves are independent in each partition, i.e. *not* connected with those of the adjoining compartments. All the sections thus give the impression of being units of their own: they are, as a matter of fact, the **individuals** of the plant. As they are all *alike* and each cares for itself—in such a way that no individual derives any advantage from its neighbours and would live equally well if separated from them—the whole thread corresponds exactly to what among the animals we called a "colony" (p. 92). The individuals of the colony, in the present case, are represented by the sections and, as we shall see presently that each section is morphologically a cell, the **whole thread** thus **reveals itself to be a colony of unicellular plants.**

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* Greek, from σπείρα,—everything that is wound, twined, and γυρός round; see the description of the chromatophore.

If we study one of the individuals under a somewhat higher power, we notice that the wall, though thin, is very sharply outlined. In contrast to the body-wall of many Protozoa it is perfectly unbroken, i.e. has nowhere any opening, and is quite immobile. It consists—for the greater part but not entirely—of a substance almost characteristic of every vegetable cell-wall and called "**Cellulose**". This is a carbohydrate, indissoluble in diluted acids and alcalis, but assuming a distinct blue or violet colour if treated, successively, with solutions of iodine and sulfuric acid (60-70 %) or, simultaneously, with a mixed solution of chloride of zinc and iodine. Both these reactions are practical tests for demonstrating the presence of cellulose.

The green structure (*Cr*, Fig. 1) appears in the shape of one or several bands with more or less notched outlines, which, immediately under the outer wall, run in fairly regular spiral lines round the axis of the cell (see explanation of the name *Spirogyra*). Occasionally, the green substance may also be found to form two star-like bodies situated in the axis and on either side of the middle of the cell. Threads of this latter description represent the genus *Zygnema*, while those with spiral bands are members of the genus *Spirogyra* proper. If comparing a number of threads collected from different localities, you will notice that the bands may exhibit variations in their number and in the relative number and density of their coils; variations which are associated with differences in the length and, especially, the thickness of the cells themselves. An important fact, however, is that these distinctions only occur between different threads, while the cells of one and the same thread are always alike and may only differ sligthly in their length. The variations here alluded to are the specific differences of the various kinds of *Spirogyra*, i.e. they determine the species within the genus. Thus, for instance, a very thick *Spirogyra* with bands forming numerous dense coils at almost right angles with the axis of the cell is *Spirogyra majuscula*; a slender form, also common in this country, with long thin cells and containing a band arranged in a few loose longitudinal coils is *Spirogyra longata*, etc.

If we place a tuft of *Spirogyra* in strong alcohol we will see that the latter gradually becomes green, while the threads simultaneously lose their colour. This therefore must be due to some substance which, in the natural state, permeates the protoplasmic mass of the spiral bands, but is extracted from it by alcohol (and other reagents). We shall see later that this green substance is of fundamental value for the life of the plant and, as it is practically the same as that which gives the leaves of all plants their characteristic colour, it has been called "**Chlorophyll**" *. Its true chemical nature is as yet still obscure, as we have thus far not succeeded in isolating it in a pure state: recent researches, however, seem to show that it is closely related to the haemoglobin of animals. Its biological value to the plant will form the subject of discussion in a later chapter (p. 263f).

This chlorophyll, in the *Spirogyra*-plant, is tied to particular band-shaped portions of protoplasm which thus

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* Greek, from χλῶρος—green, and φύλλον—leaf; therefore "the green of the leaves".

"carry" the colour and are therefore given the name "**Chromatophores**" * (*Cr*, Fig. 1). I may here state anticipatingly that essentially similar chromatophores exist in all other green plants, the differences which occur being restricted to their shape, their size and their number. While in most of the cells of the higher plants they are numerous and small (see e.g. *Cr* in Fig. 5, and *GC*, in Fig. 4, Pl. XVIII) the *Spirogyra*-cell possesses one or a few (two or three) large chromatophores of the shape already described. If we examine them more closely small brilliant granules may be seen in them at fairly regular intervals (*Py*, Fig. 1, Pl. XIV). Careful chemical investigation has shown that these consist of a central mass of some proteid-matter and a peripheral layer of tiny starch-granules. They are called "**Pyrenoids**" †.

Under a low power, and especially in certain species of *Spirogyra*, the space enclosed by the cellulose-wall, apart from the chromatophores, seems to be empty or, at the most, filled with a watery fluid. In other forms, however, we with a little trouble discover immediately under the cell-wall a thin layer of granular substance (*pU*, Fig. 1) from which fine strands, sometimes branching, or anastomosing‡ with others, start off in the direction of the centre of the cell. If closely followed, they are found to unite there into a lentil-shaped body, the axis of which coincides with the axis of the cell. In its middle, it is not hard to distinguish a round, slightly more refractive area (*N*, Fig. 1). In the structure here described, we have the **protoplasmic body proper** of the cell. This is therefore not solid and uniform as was the case in the animal cell, but reduced to a peripheral layer forming a kind of sac, or membrane, immediately under the outer cellulose-wall, and a central portion, both connected with each other by a varying number of strands of protoplasm. The spaces between these parts are filled with a clear fluid, the "cell-sap", while the refractive area in the central portion represents the nucleus, as may be proved by staining. Using the terminology we learned previously (p. 61) we may also say that the protoplasm of the *Spirogyra*-cell is "vacuolised" to such a degree as to be reduced to a thin sac enclosing (and a few strands traversing) the large vacuole inside.

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* Greek, from φέρω—to carry, viz. the colour (χρῶμα, see note *, p. 57); the term thus also applies to the pigment-cells of the chameleon described on p. 74.

† From πυρήν—grain, granule (see note †, p. 58).

‡ This word, derived from the Greek ἀναστομόω—to provide with an opening, is a technical term which was originally used for designating the irregular intercommunications which frequently exist between the main tracks of vessels, nerves, etc., in the human body, but has gradually been generalised for designating similar intercommunications between all other fibrillar or strand-like structures occurring in animal and vegetable bodies (compare e.g. p. 364).

I may here mention at once that similar conditions are found in almost all other vegetable cells, with the difference only that the nucleus no longer retains its originally central position but remains in a sometimes very slightly marked thickening of the peripheral layer, while the strands, then no longer necessary as connecting links, disappear. The cells, in this state, often seem to merely consist of the cellulose wall and a watery fluid inside; for the protoplasmic sac is so thin that it easily escapes observation. It may, however, be brought into view if we place the cells while still alive in a moderately strong solution of sugar or some indifferent salt. The solution passes unhindered through the cellulose-wall but is not allowed to go further by the living protoplasm which lies beneath; so the solution, in accordance with the physical laws of "Osmosis", will only attract from the cell water which is allowed to pass by the protoplasm. As a consequence of this loss of water the protoplasmic sac, after a slight reduction in size of the whole cell, gradually shrinks and, withdrawing from the cellulose-wall, becomes clearly visible (Fig. 2). We call the phenomenon here described "**Plasmolysis**" *; it does not, by the way, greatly damage the cells, for if brought back into pure water even after having been plasmolysed for several hours, these slowly reassume their original size and live on as before. A necessary condition for success is that we do not kill the cells by the reagent chosen, for dead protoplasm does not withhold salts or sugars (see also pp. 300 and 357). The protoplasmic sac known to the earlier observers as the "**Primordial Utricle**" (*pU*, Figs. 1, 2), and conveniently called by this name even now, is thus the **only really living part of the vegetable cell**, by the activity of which both the external cellulose-wall and the watery fluid in the vacuole have been produced.

Being the only living part of the cell, the primordial utricle is also the only part which may show **signs of life** under the microscope. The most conspicuous of these, in the animals, were the movements. You may observe a thread of *Spirogyra* as long as you like, it will not show any movements except such passive displacements as are brought about by currents in the surrounding water. But if you carefully observe a *Spirogyra*-cell under a high power, you may (but will not always) notice a slow irregular gliding of the granules (see p. 53) along both the primordial utricle and the strands leading away from it. As I have said, this "**Streaming of Granules**", in *Spirogyra*, is not always clearly discernible; the standard-object by which it is usually demonstrated are the hairs on the staminal filaments (see p. 368) of the species of *Tradescantia*, plants often used for bordering or filling flower-beds in gardens of this town and called in Arabic رأس كنه. In the cells of these hairs, the protoplasm is almost constantly in motion, as indicated by the streaming of its granules; it may also be seen that the strands which connect the primordial utricle with the central nucleus are not permanent structures, as they may be withdrawn at one place while new ones are formed in another. The whole protoplasm of the cell is thus in a similarly constant motion as we saw, among the animals, in Amoeba; only it goes on inside the immobile cell-wall.

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* From πλάσμα—see note *, p. 46, and λύω—to solve, detach; therefore: "detachment of the protoplasm".

The only other signs of life in *Spirogyra* directly observable under the microscope are the phenomena of **reproduction.** They on the whole show a very great analogy to those we have observed amongst the unicellular animals. As in these, the usual form of multiplication is the **division** of one original individual into two, initiated by a division of the nucleus. In *Spirogyra*, the daughter-nuclei, lying at first in the common central mass, by moving apart cause this latter to separate into two bodies which, however, remain near each other (*N*, Fig. 3). Meanwhile, the primordial utricle has begun to thicken in a line which runs round the periphery of the cell just half-way between the two ends, the thickening projecting inwards as a circular ridge (*pU**, Fig. 3). While this gradually increases in height a new partition-wall is being formed in its mass, commencing from the base of the ridge, i.e. from the outer wall of the cell (*PW*, Fig. 3). Ridge and partition-wall, growing higher, finally close in the axis of the cell between the two nuclei, and the new partition-wall now separates the original cell into two. As a curious fact, I may here mention that, under natural conditions, this division takes place between 11 and 1 o'clock at night. The nuclei, at first situated on either side of, and near to, the new partition-wall, soon shift towards the middle of their respective cells which subsequently grow to the ordinary size and then divide again. In this way the threads become longer and longer, but the phenomena described make it comprehensible that they do not branch nor alter their diameter.

When the conditions under which the plant flourishes cease to be present (e.g. if the pools commence to dry up, or if the temperature sinks below a certain limit), the Spirogyræ proceed to **sexual reproduction** which corresponds to the variety which in the Protozoa we called copulation. Threads in which the process is going on are usually distinguishable even with the naked eye by their twisted, curly arrangement which clearly differs from the straight and mainly parallel position of the non-copulating threads. The process itself takes place in this way (compare Figs. 4–7). If two threads happen to lie sufficiently near one another (i.e. if separated by a distance not greater than their own diameter), the wall of each cell bulges outward toward the opposite thread, the cells of which form identical bulgings in return (Fig. 4). The bulgings finally meet, but always in such a way that one cell of the one thread joins one of the other. It not infrequently happens, owing to an unequal length of the cells of the two threads, that one does not find a mate on the other side (see the three full cells in Fig. 8). In this case, it does not join as a third in the union of two, but remains inactive (a bachelor, as it were), a clear proof of the fact already emphasised on previous occasions (see p. 182f) that any normal sexual process takes place between **two** individuals only. Shortly after the bulgings of every two opposite cells have met, their cellulose-walls are dissolved at the place of contact, an open communication being thus established between them (Figs. 6, 7). From this period onward, the copulating threads more or less regularly present the picture of a ladder (Fig. 8).

The contents of the cells, in the meantime, have also undergone certain changes. In one of the threads, they commence to shrink, by gradually evacuating the fluid of the vacuole at a comparatively early period (above in Fig. 5), the contraction being accompanied by a disintegration and eventual dissolution of the chromatophores. The transformed bodies, by the connecting canals, then pass over into the opposite cells the contents of which have somewhat contracted also, but have not lost their chromatophores (Fig. 6). In the end, **every pair of individuals become completely blended into one body** which subsequently assumes a regularly ovoid shape (Fig. 7) and, by surrounding itself with a thick cellulose-membrane of its own, becomes what we already know as a "spore". Before proceeding further I must here insert a few explanatory remarks about this term.

The term **Spore** as alluded on page 137, was first used in botanical terminology for **any cell destined for the propagation of the species, and for this purpose usually enclosed in a resistant envelope.** It was of no consequence **how** the respective cell had taken its origin, nor did it matter that in certain cases even the envelope was very thin or entirely absent; we shall indeed see presently that there exist different varieties of spores. Speaking generally, they play a very prominent part in the reproduction of all lower plants, while the higher, as you know, for the same purpose form "**Seeds**". The distinctive character of these latter consists in their containing, within an outer shell, a young plant with its essential parts already developed (see p. 319). In this form, the seeds of the plants are comparable to the embryos of the animals, while the spores would rather resemble the undeveloped animal eggs. These, however, as they are "eggs", cannot of course be termed "spores", and so the latter term remains in the animal kingdom restricted to the reproductive cells, enclosed in a firm envelope, of those forms which do not possess eggs, that is, the Protozoa. Whereas therefore we ascribe spores to both unicellular and multicellular plants, they occur among the animals only in unicellular.

In accordance with their greater frequency, the vegetable spores, as mentioned above, show a number of variations as regards origin, equipment, and subsequent development; for the sake of greater precision these varieties are often given specialised names alluding to the characteristic peculiarities. The spore of *Spirogyra*, for instance, is a "**Zygospore**" because it contains what we already know as a "zygote"*, i.e. the product of a copulation of two individuals. The term Zygospore is applied to designate all spores the content of which has a similar origin.

Returning now to *Spirogyra*, the copulating threads, after the formation of the spores, still offer the ladder-like picture, but while they were at first alike, one is now completely empty (with the exception of the bachelor-individuals hinted at above) and the other contains a row of oval, egg-like zygospores (Fig. 8). It is thus clear that the constituents of a thread are all of the same sex, though no sexual distinctions can be detected between the individuals of different threads, so long as these are in their usual state. Only during copulation, those of the one thread all migrate, and thereby exhibit a characteristic of the male sex, those of the other thread remain in place and thereby mark themselves as females. Indeed we consider the migrating cells as the male, the resting as the female individuals of *Spirogyra.* I must, however, add that their particular sex is not from the beginning inherent to the cells; for it has been observed that if the ends of a long thread happen to become bent upon one another, they may also copulate, which is only possible if some individuals change from their original sex to the other.

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* Compare note ‡, p. 136.

The spores, either enclosed in the walls of the original cells, or liberated from them by accidental breaking, sink to the bottom of the water and there tide over the unfavourable season. It is a peculiarity of the zygospores in general that before developing further they go through a period of rest. At the end of this, the living content emerges after having broken the wall of the spore; by imbibing fluid (i.e. forming vacuoles) and secreting a new wall, it gradually assumes the structure of the ordinary *Spirogyra*-cell, and by successive divisions transforms into the thread from which we started in our description. You thus see that the *Spirogyra*-colony, just as it corresponds to that of certain Vorticellæ morphologically, so also develops after the same fashion as this.

2.—PLEUROCOCCUS.

The *Spirogyra* we have here described is a representative of a very large community of lower plants usually combined under the collective term "**Algæ**". In the scientific classification of the vegetable kingdom, these are distributed, according to their natural relationship, into a number of Classes and Orders upon which I cannot here enter. It, however, seems to me worth while to discuss some points of their biology, which yield interesting parallels to certain phenomena which we have observed amongst the Protozoa.

Pleurococcus.—It appears that under this denomination (and even more so under the other name "**Protococcus**") quite a number of similar, but different species and developmental stages of Algæ are combined, the specific separation of which presents extraordinary practical difficulties. If accepted in this wider sense of its name, Pleurococcus is distinguished from *Spirogyra* by the fact that the individuals do not adhere to one another in colonies, but mainly live as isolated specimens. In cooler climates (but not, so far as I am aware, in this country) the bark of trees is often seen to be more or less densely covered with bright green patches which, if looked at more closely, prove to be caused by a fine, powder-like mass. Moistening a little of the powder with water and examining it under a high power of the microscope, we find it to consist of minute green bodies which vary somewhat in shape and size. Many specimens (Fig. 1, and the lowermost individual in Fig. 2, Pl. XV) are nearly spherical or oval, but otherwise present structural details similar to those we know from *Spirogyra*. There is the unbroken cellulose-wall, in this case fairly thick, so that its outer surface may be clearly distinguished from the inner, the wall appearing "doubly outlined". Within the wall, we see the yellow-green chlorophyll tied to a chromatophore of irregular shape and apparently destitute of pyrenoids. The colourless protoplasm proper fills the space not occupied by the chromatophore, while the nucleus, invisible in the living cells, can be brought into view by staining.

Besides these round cells we find others with a median constriction of varying depth and, inside, a partition-wall corresponding to it (the second individual from below in Fig. 2). These are cells in the way of division; their descendants may even proceed to new division before they have completely separated, small irregular groups of specimens arising in this way (Fig. 2, Pl. XV). If we are lucky we may even find specimens of a third type (Fig. 3). They are distinctly larger than all the others, and within their almost perfectly spherical wall exhibit between four and sixteen isolated roundish green bodies which to all appearance are independent young individuals, though they only possess a remarkably thin wall. The destination of these young individuals is interesting.

Let us suppose that an ordinary Pleurococcus-cell be detached (e.g. by the wind) from its support and carried to some neighbouring tree. It will, under favourable circumstances, settle there and by constantly repeated divisions produce a plentiful progeny. As, however, all these descendants, enclosed as they are in their thick cellulose-walls, are completely immobile, they must stick together in one compact mass. The more this grows the more the conditions of life (by exclusion of air, etc.), will become unsatisfactory for the individuals, especially those in the centre. It would certainly be more in the interest of the preservation of the race, if the descendants were able to move away from the mother-individual, i.e. to spread on the underlying surface. They do so in fact, for we see them form even large flat patches on the bark. Here the bodies of the third of the above types play their part. The small individuals arisen by several consecutive divisions of a single mother-cell and still enclosed in its wall, if they chance to remain for some time in a moist surrounding (e.g. after a rain) escape from their prison and move about actively in the surrounding moisture. They for this purpose possess, near their anterior, slightly narrowed end, two delicate flagella which can be clearly shown by appropriate methods of preservation and staining. After roaming for some time these vagrant bodies come to rest, withdraw their flagella, and gradually grow into ordinary immobile individuals. In this way the Algæ are capable of spreading over larger areas, and we see that these humble plants, although as a rule immobile, yet under certain circumstances and for certain purposes may acquire a mobility exactly like that of the animals. The vagrant stages, being produced for the propagation of the race, are biologically "spores", though in this particular case they are unprovided with a special envelope. Since by their particular mobility they resemble animals, they are often differentiated as "**Zoospores**" (Fig. 5, Pl. XV).

The two forms of multiplication thus far described, viz. the ordinary division into two and the formation of the vagrant zoospores, are both asexual. We have pointed out on a previous occasion (p. 124) that, with a few exceptions, the asexual multiplication of an organism must at one time or another be replaced by the sexual. The rule holds good also for Pleurococcus and related forms. It is clear from the outset that the copulatory process, if it exists, can only take place between motile stages, for these alone are capable of seeking each other (compare p. 131). Thus we see indeed that the **zoospores**, at certain times, instead of settling and transforming into ordinary individuals, **proceed to copulation**. They stick to one another in pairs by their anterior narrowed ends (Fig. 6, Pl. XV), and finally completely fuse, while the four flagella of the pair are withdrawn. These copulating individuals, as in the animals, are termed "gametes"; they are, in Pleurococcus and its relatives, not outwardly distinguishable from the ordinary zoospores, and it is therefore only their conduct which determines their particular nature. But even this is not to all appearance definitive and unchangeable. For observations have shown that gametes which failed to find a mate, after some time settle down and transform into ordinary individuals, as do the typical zoospores.

The phenomenon represents an obvious parallel to the retransformation of the Plasmodium-gametes into schizonts (compare p. 147f), and both facts, in association with other similar ones, tend to prove that there is actually **no sharp and definite limit between sexual and asexual reproduction among the humblest organisms.** We are therefore compelled to assume that the former has gradually developed from the latter, and it is in evident harmony with this view that also the **sexual differences have gone through a similar development.** For, striking as they may be between the macrogametes and microgametes of certain organisms, there are cases in which they are little marked, and there are others, in which we cannot discover any. We have seen the latter fact, among the animals, in *Paramœcium* and in certain forms of Gregarinida; we see it now, among the plants, in Pleurococcus, and might see it in plenty of other Algæ if we examined them. I must here mention that these equal gametes, for the purpose of differentiating them from the sexually distinguishable "**Heterogametes**" (=Macrogametes + Microgametes), are generally called "**Isogametes**" *. They are, biologically, of great interest as they occupy an intermediary position, and supply the connecting link, between the simple asexual multiplication and the typical sexual reproduction.

The isogametes of Pleurococcus, as in the case of *Spirogyra*, by their fusion form a zygote which subsequently surrounds itself with a wall and thus becomes a zygospore. After a period of quiescence, the zygote hatches from the spore and develops into a new individual.

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* Ἕτερος—different (see note *, p. 53); ἶσος—equal.

An Alga, by the generic name of *Chlorella*, very similar in appearance to Pleurococcus, but having no motile stages, is a frequent inhabitant of the cells of various lower animals. In the chapter on *Hydra*, for instance, we shall see that this animal often exhibits a green colour which it owes to numerous individuals of the Alga in question settled in its cells (pp. 415, 419). A specimen of *Chlorella* is represented for comparison in Figure 4, Plate XV.

Volvox.

As a supplementary illustration to the phenomena above related I will here insert a short description of the life-history of an organism which, though resembling Pleurococcus in many respects, yet has heterogametes with sexual distinctions exactly as marked as are those between the eggs and spermatozoa of the higher animals.

Volvox (Figs. 7–11, Pl. XV) is an interesting genus the representatives of which to the naked eye appear in the shape of green balls, 0·5 to 1 millimetre in diameter, and are found freely swimming in the water of ditches and pools. I am not as yet certain whether or not a form of *Volvox* occurs in this country. If we examine one of the smaller specimens (Fig. 7) under the microscope it is seen to be composed of several hundreds of minute green cells embedded in a thick transparent mucous layer which has the shape of a hollow sphere. Each cell derives its colour from a roundish chromatophore (Fig. 8) and bears on its outer surface a pair of flagella which by their beating bring about a slowly rotating movement of the sphere*. The whole is again a colony of unicellular organisms which, however, differs from the colonies we thus far know by the fact that the individuals are not entirely independent, but all communicate with one another by thin strands of protoplasm (seen in optical cross-section in Fig. 8). They are thus enabled to exchange substances and help one another in cases of need; since, further, each individual by its flagella contributes a share to the movements of the whole the entire colony appears decidedly more consolidated than in the previous cases, and in this respect recalls the conditions of the multicellular organisms. This resemblance is intensified by the phenomena of reproduction.

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* The generic name *Volvox*, from the Latin "volvere"—to turn, wind, refers to this movement.

The flagella are not fully drawn in Fig. 8 ; only their basal portions being given.

The spheres for some time grow by division (and concomitant multiplication) of the constituent cells. Not all, however, take part in this process; for some, instead of dividing, are seen to increase in size, and to stand out the more clearly from the others as they soon become surrounded by a clear, spherical membrane and lose their flagella. These larger individuals, all about alike at first, begin to show distinctions as they grow. While some retain their spherical shape to the end (*E* in Fig. 7), others divide repeatedly (*Sp*, Fig. 7) and eventually break up into a large number of minute descendants which within their spherical envelope gradually assume a slender spindle-shape, and in so doing arrange themselves in such a way that, of their ends, those slightly more slender and carrying at their base a pair of flagella, are all directed towards the same side (Fig. 9). Both the large round cells and these small spindle-shaped (one of which is shown enlarged in Fig. 10), are finally voided into the surrounding water by a rupture of their respective envelopes and thenceforward behave as free gametes, i.e. copulate after the same fashion as was described on page 162 as "external fertilisation". Figure 11 shows a macrogamete with a number of microgametes penetrated into its mucous coat. The zygote, by surrounding itself with a membrane, becomes transformed into a zygospore and, after a period of rest, develops into a new *Volvox*. The original colony, on the other hand, still lives on for a time, but eventually perishes without producing new gametes.

The latter fact clearly indicates that there is, in *Volvox*, a sharp and definitive distinction between the reproductive cells—which transform into the gametes—and the ordinary body-cells—which procure the food for the colony, bring about its movements, and are capable of dividing and thereby enlarging the old body, but no longer of producing new organisms. There are no similar changes from gametes to zoospores and vice-versa, as we found in Pleurococcus. While, therefore, this latter, with regard to sexual differentiation, represents one of the lowest developmental types, *Volvox* is highly advanced and distinctly foreshadows the conditions we find in the multicellular organisms, in which the sexual cells are set aside for their special purpose at an early epoch, while the ordinary body-cells, though capable of dividing further, yet eventually die without yielding new sexual cells (see also further on, p. 409).

Apart from its life-history here described *Volvox* is a most interesting creature in another respect. We have seen that while it possesses flagella and by their help moves about in water after the fashion of the animals, it also possesses chromatophores like the typical plants. The same peculiarities are met with in a large number of similar organisms which are scientifically collected into the Class "**Flagellata**". A very singular fact, however, is that we find this Class discussed in text-books of Zoology as well as in text-books of Botany; in other words, that there is as yet no certainty as to whether its members should be considered as animals or as plants. The truth is that they are intermediate forms between the two; indeed if we review the various Flagellates at present known we find among them forms which by losing their chromatophores turn into organisms in no way distinguishable from typical animals, and find among them other forms which by withdrawing their flagella assume the structure and appearance of typical plants. If we look for an explanation of this remarkable fact it can only be found in the assumption that animals and plants, practically inseparable as they are even now in their humblest representatives, must once have sprung from a common root; in a similar way, perhaps, as two roads, starting from the same point and following the same direction for a certain distance, diverge as they run on and eventually lead to places far apart. If in biological science we maintain such a view, the fact here at issue is not our only reason for so doing; for, while we previously saw that the fundamental manifestations of life were the same in animals and plants, the striking differences observable consisting merely in a preponderance of the animal functions in the animals and a consequent preponderance of the vegetative functions in the plants, we shall see in the next chapter that the animal and vegetable metabolisms, also, though disagreeing considerably at first sight, yet have certain fundamental features in common, and thus, if duly considered, again offer the picture of the bifurcating road as used above.

CHAPTER IX.

On the Metabolism of Plants as compared with that of Animals.

We have in the preceding chapter often mentioned the growth of the plants, but have not touched upon the processes which precede and regulate it, viz. feeding and respiration. We will discuss these now, and may do so in a general form, for feeding and respiration are mainly the same for all plants. We begin with the process of

Feeding, or, as it is technically called, "**Assimilation**". If you remember what we have said about the thicker or thinner, but always perfectly unbroken cellulose-wall of the vegetable cell, you will at once see that **a plant cannot feed on solid material**; its food must be in a form in which it can be absorbed through the cell-wall, i.e. it must be **fluid or gaseous**. Here we have a first difference from the animal cell which we saw is capable of incorporating solid bodies. However, since the solids must also be liquefied before they can be transformed into new body-substance, the difference becomes reduced to the fact that the animal cell can liquefy its food inside its body, while the vegetable cell, unable to do the same, must obtain it in liquefied state.

A second, far more important difference is given in the **nature of the food**, or, at any rate, of the crude food-materials. The Protozoa we studied in the preceding chapters fed on organic material, and so do all other animals. These, therefore, in their existence depend on the previous existence of other organisms which in the case of herbivorous animals are plants and in the case of carnivorous are animals (see p. 217). These latter, in their turn, may again be herbivorous or carnivorous, but if we follow them up, in the way indicated, it will be found that, eventually, they all obtain their food from vegetable matter. A cat, for instance, in the main preys on mice and birds; the mice are herbivorous immediately and so may be the birds, but even if some of these are carnivorous, devouring, e.g. worms or insects and their larvæ, the latter, directly or indirectly, are herbivorous, and so all the food of the cat is ultimately derived from vegetable substance. In like manner, **the whole animal kingdom, with regard to its nutriment, depends on the existence of the vegetable.** If we admit, further, that all the organisms which at present populate our earth have gradually evolved, we must conclude that the first organisms that made their appearance were in essence of vegetable nature and, having no other organisms, or organic material, to feed on, were compelled to build up their bodies from **inorganic** substances. By far the greater majority of the actually existing plants have preserved this peculiarity; in other words, **while the animals require, and cannot exist without, other organisms to feed on, the plants are independent and live on inorganic substances they find in the ground or in the atmosphere.**

We have previously seen (p. 49) that living protoplasm chiefly consists of carbon, hydrogen, oxygen, nitrogen, and sulphur, and that phosphorus and certain metals, such as Fe, Mg, K, Ca, etc., may also be found in it; these constituents are consequently necessary for the growth of the plant and are required, as we saw, in a liquid or gaseous form. They are practically obtained, the carbon from the carbonic acid of

the air, the remaining elements from **water and various mineral salts** dissolved in it. Among these salts, nitrates form the chief source of nitrogen (this therefore cannot be taken from the air directly), while sulphur and phosphorus are abstracted from the respective acid-compounds of the metals. As water is also capable of absorbing carbonic acid in a large proportion, plants, if they so choose, may live in it and then obtain all their necessary food from this one medium.

The inorganic compounds mentioned, by the activity of the plant, are finally transformed into new protoplasm (and the other particular constituents of the vegetable body); they are, as the scientific expression is, "assimilated". This process, if taken as a whole, is in the main what in Chemistry we call "**synthetic**"[*], and thus considerably differs from the corresponding process in the animal organisms. For what in this we call "digestion"[†] chiefly consists in a destruction and splitting up of the organic food and is accordingly in the main "**analytic**"[‡]. However, I had to say "in the main", because observation teaches that the animal organism, in combination with its analytic activity, also manufactures certain more complex compounds out of less complex, that is, carries out synthetic processes. Since, further, the converse occurs in plants, in other words, since these, besides their building up organic substances from inorganic, also break up complex compounds into less complex, it is obvious that the difference above given is by no means absolute. We have rather to imagine that the metabolism of any living organism is an association of both synthetical and analytical processes, of which the former have gained the upper hand in the typical plants while the latter have become prominent in the typical animals. This view finds a strong support in the biological peculiarities of the Flagellata mentioned on page 257f. For as some of these organisms combine animal and vegetable characters in their outward appearance, so their metabolism cannot precisely be classified as animal or as vegetable. It practically holds an intermediary position and thus again presents the picture of the two bifurcating roads used a few pages back. It is indeed our scientific conviction that the **methods of nutrition, widely as they may seem to differ between the higher representatives of the animal and vegetable kingdoms, are yet mere variations of one and the same original process.**

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[*] Greek, from σύν—together, and τίθημι—to place, put, lay.

[†] From the Latin "digerere"—to place asunder, separate.

[‡] Greek; ἀναλύω (from λύω, see note †, p. 213)—to dissolve, disintegrate.

It is easy to convince ourselves that the bulk of the plant is made up of **carbon**; a glance at a piece of charcoal will suffice to supply the evidence. Careful measurements have shown that about half the weight of a dried plant is due to carbon. All this is taken from the carbonic acid of the air (or water). We are as yet still perfectly in the dark as to the actual chemical process by which the carbon is converted into organic matter; some important details are, however, known, and these are the following. The carbon-dioxyde, after absorption, is broken up into its constituents, the oxygen being again discharged, while the carbon is retained. The compound in which this becomes first observable in the plant is a "carbohydrate", i.e. a combination of carbon, hydrogen, and oxygen (water is practically consumed in its formation), most frequently **starch.** This occurs in the shape of small brilliant granules, a characteristic peculiarity of which, among others, is that they assume a deep blue colour if brought into contact with iodine. Iodine-solution is thus the usual reagent for proving the presence of starch in any part of a plant.

The capability of the plant to form starch depends upon two essential conditions. One of these is that it can only take place in **sunlight**, either direct or indirect. It is easy to understand that the chemical changes leading to the formation of starch require a certain power for being carried on; the sun-rays, the energy of which is known, supply that power. When it ceases to be available, assimilation ceases also. In order to obviate misunderstandings let me here remind you that even the so-called " diffuse " day-light is ultimately derived from the sun, and is thus a mitigated form of " sunlight ". There are many forms of plants which prefer this light to the direct sunlight, and therefore only thrive in shady localities, while others require intense light and wear away in the shade. In some form, however, light is indispensable for assimilation and hence the latter can go on, under concomitant exhalation of oxygen, only during day.

Next to light, the capacity for assimilating depends on the **presence of chlorophyll** (p. 242). Though we do not yet know why, the fact remains that **only the green parts of a plant can form starch.** Careful researches have even shown that the essential factor is the chlorophyll itself. For, if by artificial means it is prevented from being developed in the chromatophores, these latter alone are unable to assimilate. On the other hand, the chlorophyll does not seem to be consumed, or to be greatly altered in any other way, by its activity. In what this activity consists is perfectly obscure, but in order to get some idea as to how the whole mechanism can work under such conditions we might perhaps think of the electric accumulators, which are alike capable of taking up and holding a large amount of energy without showing great outward changes. I would point out that this is merely a comparison ; for what we at present positively know is only that the vital activity of the plant is tied to two conditions : the presence of light and the presence of chlorophyll.

Some of the facts here described are easily demonstrable. If we keep a tuft of *Spirogyra* in a basin and exposed to light for a couple of days, we will notice that air-bubbles are formed in increasing numbers, some of which remain entangled between the threads. If properly examined this " air " will prove to be more or less pure oxygen which has been liberated by the *Spirogyra* in connection with its assimilation. The starch-granules round the pyrenoids are the first visible products of the process. If, early in the morning, we partly cover a leaf of a growing plant with some opaque mass (e.g. tinfoil), and in this condition leave it exposed to the sun for several hours, then cut it off and place it in iodine-solution after having extracted the chlorophyll by strong alcohol, the exposed part will assume the characteristic blue colour due to starch, while the covered part, owing to the absence of starch, preserves its original whitish tinge (if a strong iodine-solution is used for the experiment, its yellow colour may of course more or less mask the other colours). The preclusion of sunlight has prevented the formation of starch in the covered part.

The experiment just described demonstrates another important fact. As the covered area of the leaf was not covered the day before, it must have formed starch, like the rest of the leaf which was uncovered ; this old starch, however, must have disappeared during the night, for otherwise it would have shown the blue colour also. This disappearance of the starch during night is explained if we remember that the final aim of the whole nutritive activity is the formation, not indeed of starch, but of living protoplasm (and certain other constituents of the vegetable body). This work is furthered during day so far as light cannot be dispensed with as a source of energy, the rest is done **at night.** It begins with a dissolution and simultaneous **transformation of the starch into glucose and sugar** (as to the significance of this process see further on), the natural consequence being that the starch-granules disappear from their place and make room for new ones to be formed the next day. The sugar, in its turn, serves for the final manufacture of proteids and protoplasm, a process in which the various mineral salts enumerated above are required, which contain the other constituent elements of the vegetable body. The intimate nature of these new changes is as unknown, thus far, as is that of the earlier processes.

In the aquatic plants, i.e. those living in water, the salts are alike at the disposal of all the different parts of the plant and the formation of new protoplasm may thus go on at any place, supposing that there is chlorophyll. Such favourable conditions do not exist for the “ terrestrial ” plants, i.e. those that grow on dry land. It is true that the superficial layers of the soil usually contain all the material prerequisites of vegetable life, but there is no light for the plant to make the proper use of them. So a certain portion of its body must under all circumstances seek the light, and this part will of course be green. Another part, however, must of necessity remain in contact with the soil, for the salts indispensable for growth can only thence be obtained. This part of the plant, as it cannot assimilate in the darkness, will be free from chlorophyll. So we see that the particular conditions of life given on land are bound to lead to a division of the labour and, as a consequence of the principle of functional adaptation, to a concomitant division of the body of the plant. It becomes separated into "**Shoot**" and "**Root**", the former being the green part raised above the soil and delegated to supply the food-materials obtainable from the air, the latter being the uncoloured part remaining in the soil and delegated to supply the food-materials distributed there.

You are familiar with these conditions amongst the higher plants; a very interesting example that they may also occur in unicellular plants, supposing that these live under the required conditions, is given by a small Alga named **Botrydium** (Fig. 12, Pl. XV) and inhabiting the muddy areas along the banks of rivers. Its body consists of one cell with many minute nuclei, but nevertheless shows a sharply pronounced division into a colourless, branching underground part corresponding to the root, and a vesicular, over-ground part coloured green by numerous small chromatophores, and corresponding to the shoot of the higher plants. When speaking of the unicellular animals I tried to show you that the principle of the division of labour manifests its activity even in so simply organised creatures as are *Amoeba*, *Vorticella*, and others; for in their "organula" these animals possess, within the narrow limits of one cell, differentiations which functionally absolutely correspond to the "organs" of their higher relatives. It is interesting to see that similarly primitive stages in the evolution of organs also occur among unicellular plants, and are in these due to the same biological reasons.

As the entire food, in the higher plants, is thus derived from two quite different sources (air and soil), and is supplied by parts (shoot and root) which occupy the opposite ends of the body, it is clear that **neither part can form new protoplasm and grow without the extensive help of the other.** The consequence is that in any plant, in which the specialisation into organs like shoot and root has taken place contrivances must also be found to secure an ample interchange of the substances contributed to the whole by the different organs. You will remember that in the higher animals the circulatory system complied with a similar demand; a brief mention was also made (p. 35) that, in the higher plants, there is a "vascular system" for the same purpose. The only difference is that, in the animals we find one continuous stream from one organ to the other and thence back to the first, while in the plants there are two streams, one carrying water and salts from the roots to the leaves, where they are required for making proteids, the other carrying proteids from the leaves to the roots, where they are required for growth.

You will now understand why the starch-grains formed in the leaves as the first products of assimilation are again dissolved at night under concomitant conversion into sugars (p. 264f). The material they consist of has to be distributed to those parts of the plant which cannot by themselves assimilate. As in the animals, the process of nutrition of the whole organism consists in every cell receiving its due share by way of the vessels. The vegetable cells, as we have emphasised on page 241, are surrounded on all sides by their unbroken cellulose-wall. Now supposing even that the starch-grains could travel through the vessels, they would, as solid bodies, certainly not be able to pass through the walls of the cells in which they arose, nor would they be able to enter through the walls of the cells by which they are required. Their conversion into a liquid state is therefore indispensable for transport.

These are the fundamental facts you should know of the process of nutrition as it goes on in plants. Before leaving the subject I should not omit to mention a view which, by dividing the entire process into two phases, brings the points of similarity between animal and vegetable nutrition more clearly into evidence. The first products of assimilation, as we have seen, are certain carbohydrates (starch, sugars, oils, etc.), that is, bodies which also constitute a large proportion of the food required by the animals. If, therefore, instead of the raw materials actually taken by the green plants, we would consider these bodies as their true food, a good deal of the apparent difference in the two methods of feeding would vanish, inasmuch as both animals and plants would then live on similar organic materials. We would be able to say that all living organisms, as they agree in their other manifestations of life, so also agree in their requiring essentially the same sort of food for building up their bodies. Up to this point the theory is indeed quite plausible, and, accordingly, acceptable; on the other hand, it does not remove the important difference that the organisms we call plants introduce their food in the shape of crude materials, giving it the proper form by their own activity, while the animals, unable to do the same, must obtain it ready-made. It would, I think, be ill-considered to minimise the importance of this divergence; we shall indeed see presently that it is a fact of immense consequence in so far as the existence of the whole organic world in its present form hinges upon it. In order to fully understand this it is necessary first to shortly investigate the process of

Respiration of the plants. In contradistinction to assimilation which, as we saw, in a very prominent point differs from digestion, respiration is completely **identical in animals and plants**, and accordingly bears the same name in the two kingdoms. It consists, as described on page 5, in a combustion of certain products and is outwardly marked by an **intake of oxygen and giving out of carbonic acid and water-vapour.** You will at once perceive that these concomitant phenomena are just the opposite of those which accompany assimilation in the green parts of the plant. A leaf indeed, while it absorbs carbonic acid as food, exhales the same combination as a product of respiration; and while it exhales oxygen as a by-product of assimilation, inhales it as a prerequisite for respiration. You might ask what evidence we have for assuming such an intricate, seemingly even unnecessarily intricate, state of things. I will here only point out three facts determined by numerous experiments. While assimilation is restricted to the green parts and day-time, **respiration goes on in every part of the plant and does so continually.** If we place flowers (which respire, but do not assimilate) in a closed glass-receptacle we will find that the air this contains is gradually becoming free from oxygen: the amount originally present is being used up for respiration. Again, since by the process certain substances are burnt and subsequently removed from the body (by exhalation), its going on should be connected with a gradual loss of weight. Sprouting seeds kept in the dark (and in this condition unable to form new substances by assimilation) practically become lighter. Respiration, lastly, owing to its being a process of combustion, ought to be connected with a rise of temperature. This of course cannot be exactly measured in the case of an individual plant, but if summed up artificially becomes demonstrable, just as in the case of the bees described on page 191. Sprouting seeds collected in masses are indeed a well-known example for demonstrating that respiration, in plants also, produces a rise of temperature.

General Considerations. The metabolism of the plants here described may seem insignificant by itself, and yet it is of extraordinary practical importance for certain aims of Man as well as for the whole household of nature. I will try to show this by the following considerations. The average amount of carbonic acid contained in the air is 0·03 — 0·035 %, so that in a cubic-metre of air we find about 0·3 litre of carbonic acid which weighs about 0·66 gr. (1 l. CO_2 = 1·9768 gr.). Of these 0·66 gr., about $\frac{8}{11}$ = 0·48 gr., are oxygen, and only $\frac{3}{11}$ = 0·18 gr., are carbon; by totally depriving a cubic-metre of air from its carbonic acid, a plant would thus be able to add only 0·36 gr. to its dry weight (about half of which, as we saw, is due to carbon). The average weight of cotton exported from Egypt every year is 250 million kilogr., which have a mean value of L.E. 15,000,000. Half of this weight is represented by carbon, and is taken from the Egyptian air; the amount of this latter required for the growth of the cotton-fibres would accordingly be about 347,000 million cubic-metres. As the whole of Egypt covers an area of 31,300 square kilometres = 31,300 million square metres, the atmosphere reposing on this area would have to deliver its carbonic acid up to an average height of 11 metres to satisfy the demand of the cotton-plants for developing nothing but their wool.

You thus see what considerable actual value may be derived, though in an indirect way, from the air; more striking, however, is the comparatively enormous amount of carbonic acid consumed every year in the growth of the vegetation. For the figures quoted above merely refer to the actual cotton-wool produced in this country. If we remember that this wool represents only a trifling portion of the entire cotton-plants, and that these, in their turn, make only an infinitesimal part of the vegetable organisms growing all over the land, we might infer that the whole of the atmosphere will not for long be able to supply the carbonic acid necessary for such an amount of vegetation, even if we make allowance for the fact that large parts of the surface surrounding Egypt are not suitable for vegetable growth and may thus cede their carbonic acid to the fertile country. There is indeed little doubt but that the atmosphere of the earth would soon become deprived of all its carbonic acid by the vegetable world, if there were no means to make up for the loss.

We here come to a very important and interesting chapter in the history of the general household of nature ; for as a matter of fact carbonic acid, while it is constantly being withdrawn from the air on the one hand, is on the other as constantly being poured into it from various sources. These, in part, are artificial, in part natural. The most important artificial source is the **activity of Man**. By burning wood, coal, oil, etc., for his many economic and technical purposes, he perhaps daily sends out into the atmosphere thousands of kilogrammes of carbonic acid. A feature, in the first place worth noting, is that the carbon burned in these processes is by its combustion converted into the same compound from which it was originally abstracted. For we know that the wood of a tree to half its weight consists of carbon taken from the air during the life of the tree. If we burn this wood we restore the carbon it contains to its previous condition; but we at the same time do a thing even more noteworthy. From the instance of the engine (p. 7f) you will remember that we burn wood (or any other fuel) chiefly for the purpose of obtaining energy; this therefore must be hidden, as it were, in the wood and is practically nothing else but that energy of the sunbeams which the tree when it was alive utilised for building up its body-substance. The wood thus is in some sense a reservoir of energy, and when we burn it we not only resolve it into the constituents from which it was manufactured, but also release the energy which was tied up so to speak in its formation.

The same is the case if we burn coal, or oil. You perhaps know that the coal we at present find in the depths of the earth is nothing but the charred remains of plants which millions of years ago were buried in water, mud, or earth, and in this condition so slowly decomposed into coal that their original shape and structure often remained preserved even in minute details. These plants, during their life, assimilated carbonic acid from the air as do the actually living plants; and if to-day we burn their carbonised remnants we restore this carbon to its original condition, but at the same time again liberate the energy of the sunshine, which millions of years ago was collected and stored up in the formation of the organic substance.

While the bodies of the plants of bygone periods, in the course of time, became reduced to coal, the bodies of the animals which populated the earth in the same epochs seem to have disappeared, with the exception of certain hard parts, such as bones, shells, etc. There is, however, a strong probability that the oils we at present draw from the bowels of the earth in various countries ultimately owe their existence to the protoplasmic bodies of those animals. I cannot here enter upon the several reasons which lead us to this assumption, the most striking of them are that the protoplasm, with its particular constitution, cannot have entirely disappeared within the earth, and that the various oils cannot possibly have a purely inorganic origin. If they are derived from the bodies of the animals that lived in the earlier periods of the earth, the carbon they contain must have been obtained from the atmosphere, for any animal, as was pointed out on page 260, whether carnivorous or herbivorous, ultimately obtains its food from vegetable organisms which, in their turn, abstracted it from the carbonic acid of the air. **Thus, whether we burn wood, or coal, or oil, in order to gain the energy stored in them, we produce, and send out into the atmosphere, carbonic acid which had previously been taken from it.**

These artificial sources of carbonic acid, abundant though they may be, are nevertheless insignificant as compared with the natural sources which are provided by **living organisms**. We know that the plants, while on the one hand assimilating and thereby absorbing carbonic acid, on the other continually respire and thereby produce the same compound. The production is relatively small, there is no doubt, and would certainly remain far below the proportion required by the whole vegetable world; but there are the animals, in which respiration takes place with much greater energy than it does in plants. A full-grown man, for instance, every day exhales about 900 grammes of carbonic acid, and in a year about 328·5 kilogrammes. These would suffice to fill nearly 498,000 cubic-metres of air with the average percentage of 0·66 gr. CO_2 per cubic-metre. Consequently, about 697,000 people, that is almost exactly the sixteenth part of the total population of Egypt (11¼ millions), would be required for producing the quantity of carbonic acid which is used up in the formation of the cotton-wool alone. In addition to the human race, we have the immense number of **animals,** large and small, **every one of which, by its respiration, represents a natural source from which the atmosphere draws an ever fresh supply of carbonic acid** in place of that abstracted by the plants.

There is still another equally important source; but before discussing this I must shortly touch upon a point connected with the present subject. We know that the carbonic acid exhaled by the animals is a product of the combustion which goes on in the animal organism in connection with its respiration. This fact implicitly explains the remarkable vital energies of the animals. For since these only feed on organic (ultimately vegetable) matter they must consume along with this a considerable amount of stored energy which becomes released by digestion and respiration and is, in its turn, to the larger part used up in the performance of the special "animal functions" (p. 22). This most outstanding character of the animals undoubtedly stands in intimate causal relationship to their living exclusively on organic food. In plants we know that respiration, and analytical processes in general, are much less intense, a fact which manifestly agrees with their reduced mobility and irritability. On the other hand, the mere existence of respiration in plants proves that analytical processes must play a part in their metabolism and result in production of energy. We might ask, then, for what purpose this energy should be required in addition to the far greater energy derived from the sun's rays. In reply to this question we can thus far only point out possibilities, and the one which seems the most probable is that the former form of energy is a kind of controlling power of the latter. We have on a previous occasion (p. 264) compared the chlorophyll-mechanism of the plant to an electric accumulator. Though able to consume and release enormous powers an accumulator can, when properly installed, be set to work by the force of a child. This example that Man constructs contrivances which, for his benefit, utilise and control forces of nature infinitely more powerful than his own may perhaps serve to bring the significance of the chlorophyll-apparatus somewhat nearer to our understanding. We would have to interpret it as a sort of machinery devised for making the energy of the sun's rays serviceable, but requiring for its own management only that little vital energy which the plant derives from its metabolism. It is not uninteresting to see that this interpretation, by implicitly stamping the chlorophyll-apparatus as a mere subsidiary organ for feeding, to some extent separates the manufacture of carbohydrates (starch, etc.) from the feeding process proper, and thus favours the above view that the true food of the plant is organic like that of the animals (p. 268), while on the other hand the existence of a special apparatus which enables the plants to prepare their food from the raw materials emphasises their difference from the animals which possess nothing similar.

Returning after this digression to our previous subject we said that there was still another natural source from which the air draws a large supply of carbonic acid. We know that after death the body of every organism decomposes. It was also mentioned (p. 22) that the process as a whole is subject to numerous modifications ; I must here add that under natural conditions it is greatly accelerated by organisms of which we shall have to speak more in detail in the next chapter. Details being thus of so manifold a description that their mention would lead us too far, I here limit myself to the statement that the final result of every decomposition, whether this takes one way or another, and whether it requires a few days or many years, is the splitting up of the organic substance, under concomitant oxydation, into elementary chemical compounds. While water and mineral salts (nitrates, sulphates, phosphates, etc.) disperse in the soil the gaseous products escape into the air; they may differ very much according to circumstances, but carbonic acid is always among them. **Thus the dead and decomposing bodies of organisms form a second natural source, from which the atmosphere continually draws fresh carbonic acid.**

There is thus no doubt that the air, while, in one direction, constantly losing carbonic acid, from another as constantly receives it anew. I must now call your attention to a very significant point in this interchange of material. On looking a little closer you will notice that all the actual sources of carbonic acid, viz. the burning of fuel, the respiration of the organisms, and the decomposition of their bodies after death, being processes of oxydation, must require a considerable amount of oxygen for going on unimpaired. Now, as we saw previously that the carbonic acid, owing to its being continually consumed in the growth of the plants, threatened to become exhausted without the production of a fresh supply from other sources, so we find, here, the danger of an imminent exhaustion of the oxygen in the air unless there be factors to make up for the deficiency. We practically have not to look far for such factors; for if we think of the predominant feature in the metabolism of the plants, it is at once clear that these must be very efficient producers of oxygen. So indeed **the oxygen required for the manifold processes of combustion going on in nature is prepared by the vegetation.**

If now we put together the facts exposed in the preceding pages it appears that the whole world of organisms, despite its being separated into the two large kingdoms of the animals and of the plants, is notwithstanding in wonderful harmony. So much so, indeed, that either kingdom, while it works for the other, cannot exist without it. The plants, from the carbonic acid of the air, and the water and the mineral salts of the soil, build up organic substances while simultaneously enriching the air with oxygen. The vegetable substance, as it requires the energy of the sun's rays for being formed, so retains it in a latent state (as "tension", as the expression is). The animals, by again disintegrating it, not only obtain the material for building their bodies and the energy for exercising their vital functions, but by their respiration also produce anew the carbonic acid indispensable to the plants, while the decomposition of their bodies after death, in addition to the processes of excretion during life, restore to the soil those mineral salts previously taken from it by the plants. (You here have the scientific reason for the practical custom of utilising the products of animal excretion and decomposition for "manuring" the soil, i.e. enriching it in substances necessary for a successful growth of the plants). There thus is a kind of closed circle and, within this, a **constant passage of material from the plants to the animals, and from these back to the plants.**

If we duly consider all the factors involved, we must even infer that the separation of the world of organisms into the two kingdoms was a **chemical and biological necessity.** We have previously seen (p. 262) that the special form of the present animal and vegetable metabolisms has probably become evolved from an original intermediate form. Supposing that this latter had been maintained unaltered through long periods it must with some probability have led, sooner or later, to a using up of certain materials, while others, though available also, would have been left untouched. Let us assume as an example that from some day onwards all animals without exception would turn to cereals as their exclusive food ; it is clear that in this case the fertile surface of the earth would not for long remain able to satisfy the demand for these materials, and the consequence would be that the multiplication of the animals would become ever more difficult. But it is equally clear that the difficulty would at once be remedied by some species changing to a diet of plants not hitherto used as food and accordingly available in abundance. In a like manner we may imagine that the mainly uniform metabolism of the earliest organisms gradually turned out to be a hindrance to their development, but that the separation into two varieties, in a certain sense antagonistic to each other, created the possibility of a mutual exchange of material in the form above described. As an electric current is not imaginable without a positive and a negative electricity, so it is not difficult to see that, without the existence of animals and their particular metabolism, the development of the vegetable kingdom would be as limited, as the development of the animal kingdom would be impossible without the existence and the particular metabolism of the plants. We shall in the next chapter incidentally have to speak of " Symbiosis ", a phenomenon consisting in the fact that two entirely different organisms associate themselves for life in such a way that either, while it affords a decided advantage to the other, from this derives an equally important benefit in exchange (p. 313). If we duly consider the mutual relations between animals and plants, as they have here been exposed, it seems not exaggerated to say that the two kingdoms represent the most magnificent example of a symbiosis that can be imagined.

In the preceding discussion I have taken into account only that form of vegetable metabolism which is the most common, and consequently must be considered as the normal. There are, however, some very important deviations from it, which deserve special attention; they will form the subject of the following chapter.

CHAPTER X.

On Saprophytes and Parasites.

Ever since organisms lived on the earth they died, and decomposed subsequently. Theoretically considered, their body-substance, having become masterless after their owner's death, represented a material which might well serve as a convenient and easily obtainable food for other organisms. So it is not strange to see that there actually were quite a number of animals and plants which seized upon it as their normal nourishment. We at present combine these under the collective term "**Saprophytes**"*; it goes without saying that this name does not indicate any natural relationship, but merely serves to circumscribe a number of organisms which agree in the particular nature of their nourishment and the particular manner of acquiring it. With regard to the latter point it is to be noted as essential that true saprophytes mainly feed on liquid products of decomposition and appropriate these, either by sucking them up into digestive organs, if these exist, or else by simply absorbing them through their body-walls. It is customary in certain classes of the human society to eat game in a more or less advanced state of decomposition; also insane people sometimes are in the habit of devouring all sorts of foul things. We cannot in these and similar cases speak of a true "saprophytism" for the two reasons that the decomposing objects are not the normal food of the respective persons, and that they are devoured before complete liquefaction. **True saprophytes are only such organisms as normally feed on the liquid products of organic decomposition.**

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* **Greek, from σαπρός—foul, stinking, and** φύτον (from φύω—to grow)—growth; φύτον, in scientific terminology, is the usual designation for "plant" in contradistinction to ζῶον—animal.

Within the limits drawn by this definition the saprophytes exhibit considerable diversity. They as already stated may be **animals as well as plants.** It is probably known to you that the dead body of some large animal, if left in the open, especially in the warm season, after a few days is alive with active "worms" or "maggots", and that similar creatures often also appear in cheese, fæcal deposits, etc., etc. They are the **larvæ of various kinds of flies** such as usually collect in the neighbourhood of, and settle on, offensively smelling objects. The life-history of these flies is biologically a development by metamorphosis, in principle identical to that of the mosquitoes (p. 211), the bee (p. 192), and the silkmoth (p. 187). A peculiarity of the flies under consideration is that their larvæ are true saprophytes; for their normal food consists in the decomposing and putrefying bodies of other organisms (chiefly animals), within which they grow with astounding rapidity (see here the remarks on page 219 about the general peculiarities of the food taken by " larvæ "). We know a number of similar saprophytic species belonging to various groups of the animal kingdom; considering the work achieved by them from the human point of view, we must acknowledge all as extremely useful creatures; for, while the dead body of e.g. a donkey, if left to itself (as one may often enough observe in the neighbourhood of the villages of this country) would poison the air of its surrounding for weeks and possibly months, it is by the activity of fly-larvæ disposed of, and the cause of the offense removed, within a few days. The metabolism of these saprophytic animals does not show any particular features, but is in the main analytic and the same as that of their ordinary, so-called "free-living" (carnivorous or herbivorous) relatives.

The **saprophytic plants** are by far more numerous than the saprophytic animals. Being saprophytes, they of course share the characteristic mode of life of the latter; a very important point of general biological interest is, however, that in so doing they alienate themselves from their original relatives. While the saprophytic animals, as we pointed out, with regard to their metabolism do not essentially deviate from the free-living, **the normal metabolism of the plants becomes more or less fundamentally altered by the saprophytic mode of life.** Living as all saprophytes do in a fluid containing dissolved organic compounds, the saprophytic plants need not build up these compounds by their own activity and accordingly **require neither light nor chlorophyll** for their growth. We practically find their bodies free from chlorophyll, and see them thrive equally well in the light and in the dark. As a consequence of the absence of the chlorophyll-apparatus, there is in the saprophytic plants nothing of that synthetic activity which represents so marked a character of the "free-living" plants; their metabolism, commencing with a splitting up of organic matter, is preponderantly analytic. This again exercises a decisive influence on both the products proper of the general metabolism and the by-products formed in connection with it. We have seen that in the free-living plants, owing to the simple nature of the materials they consume, these products are very simple also and in the main consist of oxygen. If, on the other hand, we consider the mode of feeding of the saprophytic plants we may anticipate that the disintegration of the highly complex organic substances taken as food will lead, not only to a general metabolism similar to that of the animals (which also feed on organic matter), but concomitantly to the formation of by-products of a higher degree of complexity. Observation shows that this anticipation proves indeed to be true in a general way ; in detail, there are a number of interesting gradations, each of which depends on the particular nature of the nutrient substance and the particular species of the saprophyte. While certain forms are satisfied with, and able to live in, almost any organic substance, others must have quite definite products, either of animal or of vegetable decomposition, and flourish in the decaying mass so long only as the respective products are available.

In order to make this clear, let us imagine a piece of meat exposed to the air in a moist surrounding. Immediately after the death of the animal this meat, though no longer true living protoplasm, yet by its being made up of highly complicated organic compounds most closely resembles it. It will in this state represent a suitable food for certain species of vegetable saprophytes. Supposing that the germs of one reach the meat, their first task must be to liquefy it, for we know that they can only absorb liquid substance. The liquefaction, just as in the animals, is done by secretions; by acting on the meat they break it up chemically into lower compounds, one of which will be that which is required by the saprophytes, while the others represent by-products. The gaseous ones among these will escape into the air; from the remaining liquid mixture the saprophytes extract what they can utilise, and continue their destructive work until the whole original piece of meat is transformed, and the nutrient material contained in it exhausted. When this period is reached, the conditions of life become unfavourable for the saprophytes; they may form spores, or adopt some other means for tiding over periods of adverse conditions; at any rate, they gradually disappear from the mass. This, however, still contains all the organic compounds not up to this time utilised, compounds which may represent just a suitable food for new saprophytic species which were not able to break up the fresh meat but find the conditions for thriving now, that is, after the soil has, so to speak, been prepared for them by their predecessors. They will multiply accordingly and the decomposing mass, if examined microscopically, is then found to contain species of saprophytes quite different from those present before. Biologically, these carry on the work begun by the earlier species, producing secretions by which the organic bodies present are again broken up into simpler compounds. The end will be as already described. While the suitable compounds are gradually absorbed, until their final exhaustion puts a stop to the further growth of the new saprophytes, the unsuitable will remain, but still offer conditions such as may be required by a third set of saprophytes. These therefore will now come to the front, to be subsequently relieved, perhaps, by saprophytes of a fourth and even a fifth group, each further disintegrating the compounds left by the preceding group.

It is not difficult to understand that the saprophytes of the later groups must be satisfied with comparatively ever simpler compounds; in other words, that with regard to the nature of the food and their metabolism in general, they gradually approach the ordinary, free-living plants. We indeed know certain saprophytic plants which require for life and growth, apart from the usual mineral salts and ammonium-nitrate as a source of nitrogen, only some carbohydrate as a source of carbon; that is, a substance which according to the view discussed on page 268 also represents the true food of the green plants. In these cases therefore the metabolism of the saprophyte would not essentially deviate from that of the free-living plant; and yet the difference in their respective modes of life persists; it has led Botanists to distinguish so-called "**Autotrophic**" **Plants**, i.e. plants which manufacture their food themselves, from so-called "**Heterotrophic**" **Plants***, i.e. such as obtain their food ready-made from other sources. Among the animals we know there is no similar distinction, for these are all "heterotrophic", though with regard to the provenance of the food they fall into the two groups of the herbivorous and carnivorous animals.

If the method of appropriating the food thus sharply separates even the most primitive vegetable saprophytes from their autotrophic congeners, and places them side by side with the animals — in particular the herbivorous — this resemblance becomes intensified in those vegetable saprophytes which feed on animal matter and thus are in some sense "carnivorous". If we retrace backwards the decomposition of the meat above outlined we see both the nature of the food required by the respective species, and the compounds formed in their metabolism, becoming ever more complex until, in the forms which first settle on the meat, we find conditions corresponding to those of carnivorous animals rather than to those of plants. The saprophytic plants, if studied comparatively, thus show the important biological fact that their metabolism, from the original vegetable (synthetic and autotrophic) type, through various transitory stages quite gradually passes over into the animal (analytic and heterotrophic) type, in other words, that **the differences between animal and vegetable metabolism, so sharply marked in the free-living representatives of both kingdoms, become more or less effaced by the adoption of the saprophytic mode of life.**

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* Greek; from τρέφω—to feed, to nourish, and αὐτός—self, alone; for ἕτερος, see note *, p. 53.

We have in the preceding pages repeatedly alluded to "secretions" poured out by the saprophytes for converting the material surrounding them into a form suitable for absorption as food. These "secretions" are of a very peculiar nature without, however, being actually restricted to the saprophytes. When speaking of assimilation in general (p. 264) we mentioned, for instance, that the starch formed in the green leaves of a plant during day is dissolved and transformed into a variety of sugar during the subsequent night. This chemical change is brought about by a "secretion" corresponding to those above mentioned, only that in this case it remains and acts within the plant. It is an albuminous substance called "**Diastase**"[*]; by appropriate methods it can be extracted and studied with regard to its physical and chemical properties; its particular action is the conversion of starch into some form of sugar. Beside it, plants may elaborate other similar combinations which each have a different, but quite definite action. We scientifically combine all of them under the name "**Ferments**" or "**Enzymes**"[†]; their most outstanding **common** peculiarity is that they **are capable of transforming any quantity of some organic substance into another, without being themselves altered or consumed during the process.**

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[*] From the Greek διάστασις—the act of falling asunder, separating, etc.

[†] "Fermentum" (Latin) and ζύμη (Greek) both mean the leaven (Arabic خمير) from which bread is made.

This characteristic of the ferments will become clearer by the following comparison. If we add a drop of of diluted sulphuric acid to, say, a litre of a solution of baryum-chloride, baryum-sulphate will be formed ; but as the sulphuric acid is consumed in the process this latter must cease with the exhaustion of the acid, while the surplus of the baryum-chloride remains unchanged. If, on the other hand, we add a small quantity of diastase to a large mass of starch the whole of this latter will gradually be converted into sugar, while the diastase is still present unaltered at the end of the process. Here you have the essential difference which separates the process of "**fermentation**" from an ordinary chemical transposition. We are not yet informed about its true nature, but meanwhile call the action of the ferments "**catalytic**"[*].

Beside the diastase, as already mentioned, various similar ferments, each endowed with a capacity of its own, are formed, according to exigencies, in the vegetable organism. One of the most interesting, undoubtedly, is a "**proteolytic**"[†] ferment by which the proteid-substances of the animal body are dissolved. We saw above that the saprophytes which first settle on decaying animal matter (p. 283) had to begin their work with a liquefaction of that matter. It is done by a proteolytic ferment. But not only saprophytes, even certain higher and otherwise "free-living" plants are capable of forming a corresponding ferment for the purpose of "digesting" animal bodies. You have perhaps heard of the existence of so-called "insectivorous"[‡] or "fly-catching" plants ; they occur chiefly in moist tropical countries (none unfortunately in Egypt) and by particular contrivances usually developed on, or by, the leaves catch small insects which happen to settle on them. By pouring a proteolytic ferment over them from special hairs they gradually dissolve the insects and absorb the albuminous solution as a nitrogenous food through the same hairs. Thus ferments play a very important part in the metabolism of the plants, but quite especially in the saprophytic, the destroying capacities of which have their material cause in the production and action of ferments.

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[*] Greek, from κατάλυσις—dissolution, destruction.

[†] A ferment which "dissolves proteids", see λύω, note †, p. 213.

[‡] Formed after the fashion of "carnivorous", etc., see note *, p. 217.

At the period of incipient decay, the organic material fed on by some saprophyte, as already stated, is still most similar in composition to the living substance. Under these circumstances it appears easy to imagine that the saprophyte might also be able to feed on the same substance of the **living** organism, if by some accident it should be transferred into it. In order to be more clearly understood let me suggest that a tree has received some injury and sap is oozing from the wound. This sap is lost to the tree, but might still serve as food for, e.g., a small saprophytic plant. Supposing that the germs of one happened to reach the sap they will flourish in it and, by multiplying, say, after the fashion described on page 252 of Pleurococcus, will eventually finish all that has been extruded from the bark. At that time the specimens, if they can, will accumulate round the wound from which their food comes, and some may even make their way into the injury and thenceforward abstract what they want for growth from the **living tree.** The chemical differences between the sap outside, and that inside are certainly not very great, and the change can therefore easily be made. Occurrences like those here assumed may equally well take place on the body of animals, from which blood or some other fluid oozes, and is appropriated by saprophytes; but the important point they show is how an otherwise typical saprophyte may under certain circumstances turn into as typical a "**Parasite**". The sap oozing from the tree and the blood oozing from a living animal are lost to the respective organisms, whether or not they are consumed by saprophytes; these latter are not therefore responsible for the loss and do not inflict any damage upon tree or animal. But as soon as they actually invade these organisms during life they do harm by violently abstracting integral parts of their bodies and thus exhibit what on page 134 we characterised as the distinctive peculiarities of the parasites.

What has just been described as an imaginary case is actually done by various forms of saprophytes. Reserving examples from the vegetable kingdom for a later occasion, I will here state that the **fly-larvæ** mentioned above not infrequently change from their usual saprophytic mode of life to the parasitic, and thereby turn into what we call "**Occasional**" or "**Facultative**" **Parasites**. You will learn later that ulcerating areas of the skin, or organs like mouth, nose, ears, genital parts, in a state of disease, may discharge a badly smelling pus. This attracts female flies and induces them to depose their eggs as they otherwise do on decaying and smelling organic refuse. The larvæ hatched from the eggs at first feed on the pus and then are true saprophytes. As they grow, however, they soon finish the pus and then penetrate into the surrounding sound tissues, devouring and destroying these and thereby turning into parasites.

Instances like that afforded by the fly-larvæ are numerous also among the plants; some, as already hinted, will be specially discussed hereafter. They all tend to show that **there is in reality no sharp limit between the saprophytic and parasitic modes of life**; in other words, that both must have evolved from a common source. We find absolutely the same conditions when comparing the saprophytic and parasitic habits with those of the ordinary ("free-living") organisms. There is no sharp limit to be found between them. I will in proof of this first recall the instances of the mosquitoes (pp. 212ff) and the flies. While the former are free-living (feeding on small vegetable organisms) in their larval stage and are typical parasites as adults, the latter present the inverted picture, being parasites as larvæ, but free-living as full-grown insects. Here therefore the single individual during its development changes from free life to parasitism, or vice-versa. Examples of animals changing between ordinary and saprophytic lines are afforded, among others, by *Paramœcium* and allied Infusoria. Though chiefly flourishing in water permeated with the products of organic decomposition, they often in their food-vacuoles present small algae devoured after the fashion of the free-living animals. Many plants provided with chlorophyll and thus capable of assimilating in the usual manner yet avail themselves of the products of vegetable decay if they have the opportunity to do so, and with their roots even attack other plants growing in the neighbourhood, to rob them of their nutritive fluids. Such plants therefore are simultaneously free-living, saprophytic, and parasitic. Lack of time prevents me from discussing these interesting biological facts in more detail; suffice it here to state that the three modes of life, as they are at present nowhere separated by sharp lines of demarcation, and gradually pass into one another, must as gradually have sprung from one another in the course of organic development.

In contrast to the "occasional" parasites which, as indicated by their name, exhibit parasitic tendencies only on certain occasions but otherwise are non-parasitic, by far the greater number of the true parasites are "**Compulsory**" or "**Obligate**" **Parasites**, i.e. they **must** live at the expense of some other organism —their "host" (p. 134)—which they deprive of its nutrient fluids, or other necessary parts of its body. This parasitic mode of life is in many cases obviously the consequence of a considerable difference in size between parasite and host. The cat feeds on mice and is large and powerful enough to kill and completely devour a mouse if it is hungry. But the mouse, supposing that it had carnivorous habits and a predilection for cat's meat, would neither be able to kill a cat nor to entirely devour it. It would, under these conditions, content itself with stealing upon it and trying to abstract some part of its body without any further aims upon the cat's life; the same thing which we see the parasitic mosquito (or flea, etc.) actually do to its host. If we compare parasites and hosts with regard to their size we indeed find that most of the former are small, the latter large, and the reason for this circumstance may well be the one just hinted at.

Owing to the usually small size of the parasites the damage done to the host by an individual specimen is insignificant, and may easily be borne; but it is clear that if the number of specimens increases the harm done will increase accordingly. In addition to the subs-traction of valuable food-materials, many parasites exercise a prejudicial influence upon their hosts by their **products of metabolism**. What we have said above about the activity of the saprophytes (based upon the action of the ferments they elaborate) is equally valid for many parasites, and when the products of this activity are emptied into the body of the host, they often act as veritable poisons. We then call them "**Toxins**"[*] and speak of a **toxic influence of the parasites. This, as we shall see later, is often by far more fatal to the host than the loss of food caused by the invading parasite.** Under these circumstances it is comprehensible that the parasites in general, if considered from the human standpoint, are noxious organisms, except in the several cases where they attack and destroy hosts which in some way or other interfere with the aims of Man.

The parasites, as already stated, may be animals or plants. We in the former case speak of "**Zooparasites**", or parasitic animals, in the latter of "**Phytoparasites**"[†], or parasitic plants. As the hosts, also, may be animals or plants, the whole parasitic kingdom, as we might call it, falls into four categories of representatives, namely, (1) Zooparasites (*a*) on animals, (*b*) on plants; (2) Phytoparasites, (*a*) on animals, (*b*) on plants. In order to give you a faint idea of the various pictures parasitism may offer to the observer, I will illustrate each of the four categories by a few special examples.

Beginning with 1 *a*, the **zooparasites on animals**, you already know *Opalina*, *Gregarina*, *Plasmodium*, the mosquitoes, the Nematode and Trematode worms. They all are parasites, but on comparison you will notice that their parasitic habits vary considerably in degree. The mosquitoes, for instance, in the main behave as free-living animals and only reveal their true nature during the acts of feeding. After the individual act is finished they withdraw from the host, not to seek it again until new food is required. We find similar habits in the fleas (برغوث), the bugs (بق), etc., while lice (قملة), mites and others, when once they have found a suitable host, remain on it for the rest of their life. We occasionally express this difference by the terms "**Temporary**" and "**Stationary**" **Parasites**, the meaning of which should be clear without special explanation. All these animals, further, establish themselves on the body-surface of their hosts, while the various Protozoa and worms mentioned above withdraw to the internal organs; for convenience' sake, we often call the two categories thus distinguished "**Ectoparasites**" and "**Entoparasites**" respectively. These terms, as several others previously quoted, do not mean to comprise communities of natural relatives, but merely indicate that the forms concerned outwardly agree in their general "habitat" *.

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[*] Τόξον—originally bow and arrow, but also the poison with which arrows were imbued.

[†] From φύτον—see note *, p. 280.

The **zooparasites on plants,** 1*b*, have representatives in the plant-lice of which we spoke on page 198. What was said there of the nature of their food and the manner in which it is acquired is proof that they are true parasites. A creature closely allied to the plant-lice is fairly common in this country. It attracts attention by its snow-white colour and woolly aspect due to fine threads of wax secreted from the body-surface (whence its vulgar name "wool-louse"); in places it covers leaves and twigs of trees in large numbers. You may in such cases easily convince yourselves of its pernicious activity, for the apical parts of the twigs beset with wool-lice often strike the observer by their poor condition and scanty growth; they cannot indeed thrive because the lice take all their

* From the Latin "habitare"—to live, dwell; it is the usual expression for indicating the place, or locality, in which some organism lives.

food away. Some other zooparasites on plants may at times gain a considerable practical importance by developing in masses and then so thoroughly abstracting the saps of their host-plants that these eventually die from starvation. You have perhaps heard that not so many years ago the vine-yards in several parts of Europe were more or less completely destroyed, and an immense damage was inflicted upon the general prosperity of the countries concerned, by a small animal which has since then become notorious under the name "Phylloxera". You will understand how this minute organism was able to do such harm, if you learn that it is a parasite on the vine. In this country, we have within recent years had the "Banana-disease" of the environments of Alexandria and the "sugar-beet-disease" of certain parts of Upper Egypt, both having stopped, temporarily or entirely, the cultivation of the respective plants on a large scale. They were caused by parasites, in this case small Nematode-worms, similar to the *Strongyloides stercoralis* (p. 206).

The **phytoparasites on animals** (category 2 *a*) only belong to the lowest Classes of the vegetable kingdom. Among them, the "**Bacteria**" or "**Fission-Fungi**" rank first, both in number of species and practical importance. As we are going to study them in somewhat more detail in the following chapter it may suffice here to mention them. The other phytoparasites on animals are chiefly represented by "**Mould-Fungi**". Most of these are simple saprophytes on decaying animal or vegetable matter, and some will be known to you in the shape of the "mould" which often develops on bread, cheese, fruit, and other victuals. Under the microscope, they usually appear as fine colourless threads which present a somewhat unequal diameter and an irregular, often branched course (Fig. 15, Pl. XVI), and after various methods (upon which I cannot here enter) separate from their main bodies minute, round spores. These, as many other spores, possess a great resistency against adverse conditions, but if transferred (by wind, dust, direct contact) on to suitable media give rise to fresh formations of mould. Some of these mould-fungi have, however, abandoned their original saprophytic habits and have turned into true parasites causing distinct diseases, chiefly of the skin, in plants, animals, and Man. As special examples I will here mention that the fungus *Achorion schoenleini*, by its growth between the epidermal cells of the scalp of Man, produces "**Favus**" or "Tinea favosa"; that the fungus *Trichophyton tonsurans* (Fig. 15, Pl. XVI), living in a similar manner in the epidermis of the face and other parts of the body, causes one of the eruptions known as "**Herpes tonsurans**" or "Ringworm", while the parasitism of *Discomyces madurae* leads to a deformation of, and eventual complete destruction of the tissues in, the feet, known under the name of "Madura-foot". In all these, and similar cases, infection with the diseases takes place by an accidental transfer of living spores into a hitherto sound epidermis.

The **phytoparasites on plants** (category 2 *b*) have the largest number of their representatives again among the Bacteria and Fungi. Some, however, belong to the higher plants and then in structure and habits so clearly illustrate the true inwardness of the parasitic mode of life that it seems worth while to say a few more words about them. A parasitic higher plant fairly common in Egypt is the "broom-rape" *Orobanche* (*minor* and other species), called هالوك by the fellahin. It occurs, often in dozens of specimens not far from one another, in the fields grown with beans, lentils, or clover, and at the first glance differs from these bright-green plants by its yellowish-white colour. The thick, straight stalk is entirely unbranched and in place of the usual leaves bears a number of small scales hardly standing off from the stalk, while along the top-portion there are several rows of pale violet flowers. The attentive observer, on seeing this plant in a field, cannot fail to notice that the beans or lentils in its immediate neighbourhood are in singularly poor condition or even altogether dead and dry. The peasants indeed know that the "halûk" damages and eventually destroys them. The observation is explained by the fact that the "halûk" is a parasite on the beans and other plants. Its stalk, though actually emerging from the earth, is, underground, continued into a root which, instead of spreading like that of free-living plants, seeks and inserts itself into the roots of the neighbouring beans, abstracting from them all the nutritive fluids which the beans prepared for themselves and meant to use for their own growth. Deprived of the results of their labour, they slowly starve, while the "halûk", thriving on the stolen ready-made food, requires neither large surfaces for absorbing a sufficient amount of carbonic acid (whence its lack of normal leaves), nor does it want chlorophyll for assimilating (whence the absence of the ordinary green colour).

While the broom-rape still possesses roots, another parasitic plant, the "dodder" [*Cuscuta* (*europœa* and other species); in Arabic حمول], very common in many parts of Europe and also occurring in this country, is so far advanced in its parasitic habits that it can altogether dispense with roots. It presents the shape of long, green threads, about half to one millimetre thick, which, e.g. in a clover-field, twine tightly round the stalks of a clover-plant, then pass over to another which is similarly caught in its close embrace, and so on, sometimes for a distance of metres. There is, in the "hamûl", hardly any trace of leaves, nor is there any root to be found; the threads at certain intervals only bear small bunches of inconspicuous flowers. If, on the other hand, we try to uncoil the twisted portions we will find that they are more or less firmly attached to the underlying stalks of the host-plants by numerous small outgrowths which on close inspection even prove to penetrate into the stalks. These outgrowths (scientifically called "Haustoria"*) are the true nutritive organs of the "hamûl", and from the stalks of the host-plants abstract ready-made food-material, as we saw the roots of the "halûk" do from the roots of the beans. *Cuscuta* possesses chlorophyll and is therefore able to assimilate; but notwithstanding, owing to the absence of leaves and roots, it would not be able to live on its own labour.

The preceding general remarks on saprophytism and parasitism will be further illustrated by the following detailed descriptions of the Yeast-Fungi and the Bacteria.

1.—THE YEAST-PLANT, OR YEAST-FUNGUS.

(*Saccharomyces cerevisiæ*).

Morphologically, this organism may be described in a few words (compare Fig. 1, Pl. XVI). It presents small roundish or oval colourless cells of an average diameter of 0.01 millimetre, surrounded by a thin cellulose-membrane and containing a slightly granular protoplasm with one large, or several small vacuoles. The minute nucleus only comes into evidence by special methods of preservation and staining. These cells multiply by budding; under certain conditions (scanty food, low temperature), the buds separate from the mother-individuals before producing new buds; we then find the cells as a rule isolated. Under other conditions (abundant food, higher temperatures), the buds proceed to the formation of new buds before their detachment from the mother-cells; in these cases, we find the individuals often united in small rosary-shaped or branching colonies as visible in Figure 1. Under unfavourable conditions (absence of food, approaching desiccation of the medium), the cells, within their membranes, break up into four daughter-cells which in some species have been seen to copulate in pairs of two before developing into spores. The process is obviously a sexual reproduction, similar to the autogamy described on page 149.

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* From the Latin "haurire"—to scoop, draw (water, etc.); can shortly be translated "sucking-organs".

The most interesting feature in the biology of the yeast-fungi is their metabolism; for they are an example of those saprophytes of which we said on page 283 that they require definite substances for their growth, and flourish so long only as these are available within the surrounding medium. The normal food of the yeast-fungi, instead of carbonic acid and mineral salts as in the free-living plants, are the ready-made sugars and proteid-substances occurring in certain parts, especially fruits, of other plants. In cases of emergency, however, the fungi, on the one hand, seem to be able to themselves manufacture some sugar from starch, and, on the other, can abstract their nitrogen from simpler compounds than proteids, such as ammonium-tartrate or ammonium-carbonate; but unless these substances (and the mineral constituents otherwise present in the proteids) are at their disposal they cannot grow. Considering the nature of this food it becomes comprehensible that the yeast has neither chlorophyll nor does it require light for assimilating food. The latter is prepared for absorption by a ferment, termed "**Zymase**" or "Alcoholase"*, which decomposes the sugar into carbonic acid and alcohol. While, however, the fungi, in their own growth, consume only a small proportion (about 1 %) of the sugar present, the particular action of the ferment (p. 287) causes the whole of the latter to break up into the compounds mentioned. With the completion of this process the fungi must stop multiplying further for lack of suitable nourishment, but they are capable, notwithstanding, of remaining alive for a long time. They even stand a considerable degree of drought, and may, if the desiccation proceeds slowly, form spores; but they do not thrive anew unless they obtain fresh sugar to feed on.

The yeast-fungi, by quickly destroying a food-store which otherwise might have served them for a long time, thus in a certain sense seem to act against their own interests; it is, however, as likely that the action is only a means of self-preservation adopted to withdraw the food-store from the reach of more powerful competitors which by seizing upon it would perhaps altogether destroy the fungi.

We at present know several species of the genus *Saccharomyces* †; they all turn sugar into alcohol, but occur naturally in sugars of different origin and are accordingly of a greater or lesser practical importance. Thus one species occurring in the soil of vine-yards and converting grape-sugar into alcohol is used in making wine; other species are utilised for obtaining alcohol from the remainders of sugar-cane, or from corn, maize, potatoes, etc.

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* Because it produces ζύμη (see note †, p. 286, and, further on, note ‡, p. 310) and alcohol.

† Greek, from σάκχαρ—sugar, and μῦκος—fungus, mucus; the term alludes to the habitat of the organism.

Perhaps practically the most important species is *Saccharomyces cerevisiæ* *, the "beer-yeast"; in contrast to its congeners it is known only in the cultivated condition, and large establishments at present make it their business to produce it in pure state for technical purposes. You probably know that beer is made of the grains of barley. Being seeds, these contain the usual proteid-substances, a large amount of starch, and, besides, traces of diastase which, when the seeds commence to germinate, gradually transform the starch into sugar and thus, in combination with the proteids, enable the young plants to develop their first leaves and roots without the help of chlorophyll and light (for some further details of the sprouting-process see later, p. 324). In the natural course of events, however, the sugar formed in the way described, as indeed it is required by the developing plant, is retained within the seeds by the living protoplasm of their cells. In order to allow it to escape the protoplasm must be killed. This is done by heating; subsequent immersion of the killed seeds into water enables the latter to extract the sugar through the dead protoplasm (compare pp. 245, 357), along with some soluble proteids. By finally subjecting the sweet fluid thus prepared to incomplete fermentation by the addition of beer-yeast, beer is obtained. This consequently contains, in addition to the newly formed alcohol and carbonic acid, certain amounts of not yet converted sugar and the original proteids of the barley. Stronger alcoholic beverages and pure alcohol are prepared from similar fluids after complete fermentation and subsequent distillation.

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* "Cerevisia"—late Latin term for beer.

You certainly know that beer-yeast is also used by bakers for making the dough of the bread " rise ". This " rising " is due to the carbonic acid produced by the yeast-fungi; in this case, from a small amount of sugar which is formed from the starch of the flour by the traces of diastase contained in it (see above). The carbonic acid is retained in smaller or larger bubbles within the dough and thus makes it swell; the holes in the bread are these bubbles " fixed " by baking. Occasionally, the dough does not rise; this fault is usually due to the application of dead yeast which naturally causes no fermentation and no formation of bubbles of carbonic acid.

2.—The Bacteria, or Fission-Fungi (Schizomycetes[*]).

(Microbes[†], Microorganisms).

This is a very large Class comprising the lowest vegetable organisms at present known. With regard to the technical names it appears that the terms " Microbes ", " Microorganisms ", are every now and then used in a somewhat wider sense to include also the lowest forms of the animal kingdom. Some of our previous discussions have indeed shown that just the humblest animals and plants, sharing as they do certain otherwise differential characters and thereby indicating their origin from a common source, are by no means always easy to differentiate (p. 258). The Bacteria, also, though now acknowledged as plants, have at some time been considered as animals. This uncertainty of the determination induced authors to establish the separate kingdom of the "**Protists**"* for all these forms of intermediary nature; but the proposal has not met with universal acceptance, chiefly on account of the fact that in place of the one previously indefinite limit between animals and plants the recognition of the Protists as a third kingdom entailed the necessity of two delimitations (viz. between Protists and animals and Protists and plants) which experience taught could not either be sharply drawn. On the other hand, the term "Protists", as it represents a convenient common designation for both the humblest (unicellular) animals and plants, has been retained in this sense; whereas "Microbes" and "Microorganisms", in their original meaning, are equivalent to Bacteria and should not be used except for the designation of these.

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[*] From σχίζω—see note *, p. 145, and μῦκος—see note †, p. 299; the term is thus the Greek for "fission-fungi".

[†] From μικρός and βιόω—see p. 2.

Bacteria were first seen long ago (1683, by Leeuwenhoek, a Dutch naturalist), but our knowledge of their biology and their immense practical importance actually dates from the time (1881) when Robert Koch, by inventing the methods of obtaining them in "pure culture", started the science now known to every layman as "**Bacteriology**". Wherever in nature a process of organic decomposition is going on, the Bacteria develop in immeasurable multitudes, for they are the organisms alluded to on page 275, through the action of which the dead organic material is decomposed with relative quickness into its inorganic constituents. But if we try to study the Bacteria as they occur under natural conditions, we find almost every material invaded by individuals, so varying in shape and relative number, that any attempt at differentiating definite species and determining their development and their biological properties appears vain. Bacteriology as an exact science thus depends on the existence of reliable methods of isolating the individuals and keeping their descendants strictly separated from foreign invåders for any lapse of time. You will be made acquainted with these methods later in your special Bacteriology-lectures; at this place, we will try to delineate a concise general picture of what they have taught us with regard to the biology of the Bacteria and the part these play in the household of nature.

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* Derived from πρῶτος—see note *, p. 46.

The Bacteria are the **smallest organisms** at present discernible under our microscopes; hence the designation "Microorganisms". I will here mention by the way that we have irrefutable proof of the existence of still smaller organisms which, however, are so minute that the highest-power-lenses, for technical reasons, do not suffice to bring them into evidence. These organisms for the time being are designated "ultramicroscopical"*. The Bacteria are visible, but still are so small that the diameter of many little exceeds, or even remains below, 0·001 millimetre. They all possess a fairly sharply drawn wall and inside a colourless protoplasm. Opinions still differ whether this should be interpreted as cytoplasm, or as karyoplasm; the fact that all Bacteria exhibit a very strong capacity for taking up stains would speak in favour of the latter alternative. Certain forms, on the other hand, allow us to distinguish within their bodies several darker granules and a lighter substance, and the question has been discussed whether these granules might not be so-called "**Distributed**" or "**Scattered**" **Nuclei**. I simply mention these details, without venturing to give a definite opinion. If placed in salt-solutions of various strengths many Bacteria show the phenomena of **plasmolysis** as described of *Spirogyra* on page 245.

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* From the Latin "ultra"—beyond.

If we examine **living Bacteria** suspended in a fluid they more or less clearly show a fine irregularly trembling movement, by which the relative position of the specimens is not, however, noticeably changed. As other granules which happen to be in the neighbourhood, or granules of carmine, indigo, etc., if examined under similar conditions, exhibit exactly the same movements, it is clear that these are not proper to the Bacteria, but originate from the surrounding fluid. We distinguish this "passive" form of movement as "**Brownian**" or "**Molecular**" **Movement.** While it is shown, under suitable conditions, by all small corpuscles, certain forms of Bacteria display movements which are manifestly brought about by their own activity, i.e. are "active", and lead to distinct changes in the relative position of the individuals. They vary somewhat in details, but are all due to exceedingly delicate **flagella**, invisible in living specimens, but demonstrable by particular methods of staining. The number and distribution of the flagella differ considerably, but three chief types may be distinguished. There are Bacteria with only one flagellum at one pole (**Monotrichous**[*] **Bacteria**, e.g. the cholera-vibrio, Fig. 7, Pl. XVI), while in the cases where more are present these may be arranged in a tuft at each pole (**Lophotrichous**[†] **Bacteria**, e.g. *Spirillum*, Fig. 8, Pl. XVI), or may be about equally distributed over the body-surface (**Peritrichous** * **Bacteria**, e.g. the hay-bacillus, the bacillus of typhoid fever, Fig. 5, Pl. XVI).

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[*] From μόνος—one, and θρίξ—see note *, p. 97.

[†] From λόφος—tuft.

The **reproduction** of the Bacteria, according to our present knowledge, takes place **only by division** (whence the name " fission-fungi ") ; in other words, a sexual act has not yet been observed in their life-history. The individuals after division either separate, or remain united in loose groups, or finally form real biological colonies of various shapes. In certain cases, also, the cell-walls swell up into a mucilagineous substance, within which the descendants remain embedded, the whole then recalling the aspect of frog-spawn (Fig. 12, Pl. XVI). We call such aggregates " **Zoogloea** " †. When the food-material commences to become scarce many Bacteria proceed to **sporulation** (compare note * on p. 144). The living contents of the cells, withdrawing from the wall, contract to form a round, brillant body which surrounds itself with a new wall **within** the old. The spore thus formed may in the various species differ with regard to its relative position within the original wall and hence we sometimes differentiate " **Endospores** " ‡, lying in the centre of the body (Fig. 13, Pl. XVI), from " **Telospores** " §, lying at one pole of the body (Fig. 14, Pl. XVI). Each Bacterium in this way forms **one** spore only; or, more precisely speaking, it transforms itself into a spore. The entire process of sporulation, therefore, unlike the similar process in the Protozoa, is no longer a process of " multiplication ", but simply a means for tiding over periods of adverse conditions in the surrounding. The spores of many Bacteria, in accordance with this purpose, possess an astounding resistance, though the limits vary with the different species. A famous example of great (but not the greatest) tenacity is supplied by the spores of *Bacillus anthracis*. These do not seem to be killed by any cold, and, on the other hand, stand a sojourn of about three hours in dry air of 140° C., of five to twelve minutes in steam of 100°, of forty days in 5 per cent carbolic acid, of thirty days in ether, of ten days in 2 per cent hydrochloric acid, etc., while alcohol, glycerine, chloroform, etc., do not seem to hurt them at all. It is comprehensible under these circumstances that the spores, under natural conditions, are not killed by any agent except time; but just with regard to this we have as yet, so far as I am aware, no complete information.

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* See note *, p. 101.

† Greek, γλοιός (from γλοιά, or γλία,—glue)—sticky, slimy ; because the organisms (ζῶα) are embedded in a sticky mass.

‡ From ἐνδός, same as ἐντός,—see note ‡, p. 53.

§ From τέλος—see note †, p. 175.

The spores, just as mere dried Bacteria, small and light as they are, may be carried about by the wind with the greatest ease, and are practically present everywhere in air, water, and soil. This is the reason why any organic material will become invaded by them with almost absolute certainty if it remains unprotected even for a short time. When speaking of "spontaneous generation" (p.105) I mentioned that up to comparatively recent years the Bacteria were considered as supplying proof positive that living organisms could arise "by themselves" within foreign media, i.e. could arise by spontaneous generation. Such a belief was comprehensible so long as nothing definite was known about the methods of reproduction and spreading of Bacteria; knowing these methods as we do now we are able to show that none ever make their appearance in media which, after having been carefully freed from germs which might be contained in them, are safely protected from others which might come from outside. The various methods of "**Disinfection**" which at present play so prominent a part in our efforts to preserve personal as well as public health are practically nothing else but measures adopted for killing those ubiquitous bacterial germs which are likely to "infect", that is, to get into, and cause harm in, the bodies of Man, animals, or plants. The fact that these measures, if properly applied, practically lead to the desired effect, is in itself proof that there is no spontaneous generation of Bacteria.

Our knowledge of the **natural relationship** of the many existing Bacteria is still somewhat uncertain, and a satisfactory **classification** has not therefore as yet been found. For the time being we classify the known species chiefly according to their own shape and that of the aggregates they form during growth. In some cases, the number and distribution of the flagella, in others, certain biological properties have been utilised as additional differential characters. The differences in shape have led to the establishment of three chief types, viz. **Cocci** *, with nearly **spherical** bodies, **Bacilli** †, with **rod-shaped, straight** bodies, and **Vibrios** ‡, with **rod-shaped, curved** bodies. Each type is divided into a number of sub-types; so, within the Cocci, very small forms are specialised as *Micrococcus*, larger forms as *Macrococcus*. If the individuals arising from the division of one original, form aggregates of irregular (grape-like) arrangement

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* From the Greek κόκκος—berry, grain.

† Latin; "bacillus"—a small stick.

‡ From the Latin "vibrare"—to tremble, vibrate, etc., referring to the movements of these small organisms.

(Fig. 4, Pl. XVI), we speak of *Staphylococcus*[*]; if they arrange themselves into lines (Fig. 2, Pl. XVI), we speak of *Streptococcus*[†]. Some Cocci very constantly occur in pairs surrounded by a mucilagineous envelope which appears white in a coloured medium (Fig. 3, Pl. XVI); they are differentiated as *Diplococcus*[‡]. Among the Bacilli, some have a rather long slender shape (Figs. 5, 6, Pl. XVI), and are then generically distinguished as *Bacillus* proper, while short, stout rods are distinguished as *Bacterium* proper (Fig. 13, Pl. XVI). Various Bacilli, by consecutive divisions grow out into real, thread-like colonies; if these threads remain unbranched (Fig. 11, Pl. XVI) this is characteristic of *Leptothrix*[§]; if they branch (Fig. 10, Pl. XVI), this is characteristic of *Cladothrix*[¶]. The Vibrios, finally, may be quite short and in the main comma-shaped (Fig. 7, Pl. XVI); these then are the genus *Vibrio* proper; if longer and describing about one or two spiral circuits (Fig. 8, Pl. XVI), they are classified as *Spirillum*; if fairly long and forming numerous circuits (Fig. 9, Pl. XVI) after the fashion of a corkscrew, they are classified as *Spirochœte*[$].

In contrast to these external characters which are fairly uniform the **metabolism** of the Bacteria presents the greatest possible variations. In principle, all Bacteria are saprophytes; but the degree of their saprophytism varies so much that certain forms in their habits come very near the free-living organisms, while others have adopted so strictly parasitic habits that they can no longer thrive outside a living organism. Without going into great details I will here briefly point out some of the more important diversities which exist. Beginning with the **parasites**, the Lepra-bacillus, among others, is one which will not adapt itself to a life in any medium except the body of Man. Most of the parasitic Bacteria, however, are able to live, and perhaps even slightly to multiply, for some time outside the body of a host, in the earth, in water, etc. Although this part of their history is as yet but insufficiently known, the mere fact affords the possibility of rearing and studying the respective forms in artificial "cultures". These are in fact at present employed for the purpose on a large scale; but it has been found that even in such cultures the Bacteria will fully display their properties and vital energies only if given media and temperatures as similar as possible to those within their living hosts.

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[*] From the Greek σταφυλή—the grape.

[†] From στρεπτός—originally meaning twisted, wound; but used also for a chain of pearls wound round the neck.

[‡] From διπλός—double.

[§] From λεπτός—thin, slender, and θρίξ—see note *, p. 97.

[¶] From κλάδος—shoot, branch, twig.

[$] From σπείρα—see note *, p. 240, and χαίτη—originally the mane (of horses), but also hair, bristle, etc.

In these latter, the products of metabolism may, or may not, act as **toxins** (p. 292). If they do, the respective Bacteria cause distinct diseases, and we then term them collectively "**Pathogenic**"[*]. I may in this connection shortly allude to the biologically most interesting fact that the body of the host, if infected by some particular species of pathogenic Bacterium, reacts upon its special toxin by the elaboration of as special a **protective substance** called "**Antitoxin**"[†]. This, if present in sufficient amount and strength, stops the further growth of the Bacterium and eventually destroys it (see also p. 73). The course of the disease then is a kind of struggle between parasite and host; if the parasite, with its toxin, proves to be the stronger, the host succumbs; if the host, with its antitoxin, gains the upper hand, the parasite succumbs and the host recovers. The antitoxin, in this case, may still remain active in the host's body for a longer or shorter period and then give it what we call an "**Immunity**"* against the disease; that means, the particular species of Bacterium if reintroduced into his body cannot thrive, or, at any rate, has its products of metabolism neutralised in some way before they can act.

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[*] From πάθος—suffering, disease, and γένεσις—see note *, p. 114.

[†] From τόξον—see note *, p. 292, and ἀντί—see note †, p. 37.

Beside the pathogenic Bacteria there are others which, though parasites, are "**Non-pathogenic**", i.e. their products of metabolism have no prejudicial influence upon the host (e.g. the various Bacteria of the mouth and the digestive tract). However, this is not a rule without exceptions. The common *Bacterium coli commune*, for instance, is a harmless parasite so long as it remains in the intestinal lumen, but becomes pathogenic as soon as it accidentally enters the abdominal cavity or the tissues of the body. Other Bacteria act accordingly, and some, moreover, are pathogenic for certain hosts, but are non-pathogenic for others.

Among the truly **saprophytic Bacteria** those which first settle in dead animal substance and destroy it under evolution of offensively smelling gases (p. 283) stand next to the parasitic and may occasionally even turn into such. They are often collected into a group "**Saprogenic**"† Bacteria, which means "Bacteria of putrefaction"; but, nevertheless, are not sharply delimitable from the opposite group "**Zymogenic**"‡ Bacteria, or "Bacteria of fermentation", under which name we combine the species living in lower organic compounds, chiefly carbohydrates, and decomposing these under evolution of non-smelling gases (carbonic acid, hydrogen, methan, etc.). Some of these latter Bacteria are of great every-day importance; thus, if milk becomes sour, this is due to the action of *Bacillus acidi lactici* which turns the sugar of the milk into lactic acid; if butter becomes rancid, this is due to *Bacterium butyricum* which by its activity forms butyric acid; if beer, wine, etc., become sour, several species of "*Bacillus aceticus*" turn the alcohol of these fluids into acetic acid; the gas-(methan-) bubbles rising from the bottom of stagnant pools are produced by *Bacillus paludosus* which decomposes the cellulose of dead vegetable bodies. This latter instance is of special interest inasmuch as it tends to show that every product of the living organism—even one so resistant as cellulose is—eventually finds saprophytes which utilise it as food and thus destroy it.

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* "Immunitas", Latin, the "being free, exempt" of something.

† See note *, p. 280, and note * on preceding page.

‡ See note †, p. 286, and note * on preceding page.

Certain saprophytic Bacteria are especially concerned in the transformation of **nitrogen**. You remember that this element is present in every proteid, and is, in the animal body, also constantly excreted in the form of urine. Both proteids and urine, consequently, by their decomposition, yield nitrogenous compounds, the chief of which is, in the end, **ammonia**. The living plants, on the other hand — the animals you know obtain their nitrogen from these—for manufacturing new proteids require nitrogen in the form of **nitrates**. These therefore must be constantly supplied to any soil if it shall remain suitable for vegetable growth. In quite modern agriculture, so-called "artificial manures" are employed for the purpose; they contain nitrates (and certain other necessary salts) ready-made. But under natural conditions, as we saw on page 277 the soil receives nitrogen only through the decomposing bodies of animals after death and their products of metabolism during life; the latter in particular having been used by farmers for centuries back as "natural manure". I may here state by the way that a natural manure reputed to some extent for its efficiency is supplied by the excreta of birds and is known the under name "guano". If you direct your attention to the point you may convince yourselves with little trouble that the birds do not "urinate" in the usual sense (they practically have no urinary bladder), while their "fæces" are conspicuously composed of a brownish and a white matter. The latter represents the urine which, in the birds, is not given off in solution, but as a solid, or semi-solid substance. Hence birds' "fæces", or else the "guano", are unusually rich in urea. In the villages of this country, the excreta of pigeons (زبل حمام) are frequently collected and practically used as manure.

Now we know that the green plants can utilise nitrogen only if it is offered to them in the form of nitrates; consequently, the nitrogen contained in the various kinds of natural manure, in order to become at all available to the plants, must previously be converted into this compound. This is the point where the action of several sets of Bacteria comes in. The first is the group of the "**Ammonia-Bacteria**" which in the presence of moisture and under access of air split up the urea into carbonic acid and ammonia. The latter is subsequently acted upon by the "**Nitrifying Bacteria**" which, among themselves, fall into two categories: one converting the ammonia into nitrites, the other transforming the nitrites into nitrates and thus making the nitrogen of the original manure available to the plants. As the processes here outlined are constantly going on in the soil, independent of the interference of Man, the nitrifying Bacteria have an immense practical importance in the household of nature.

There are, however, certain others, the activity of which is even more marvellous, inasmuch as, in constrast to all other vegetable organisms, they can appropriate the nitrogen directly from the air. They for this purpose enter into a "**Symbiosis**"* with other plants, chiefly so-called "*Leguminosae*", examples of which are lupins (ترمس), beans (فول), peas (حُمُّصْ), clover (برسيم) and others. Symbiosis, shortly speaking, is a "life-partnership" between two organisms established on the principle that each partner gives something up in the union, or, at least, offers some vital advantage to his mate—an advantage which this latter would not be able to gain by his own resources—while in exchange he derives himself some important benefit from the other. As to lupins, for example, you may perhaps have heard that, in Europe, they grow very well in almost pure sand. If we glance at the root of one carefully taken from the ground, we often see that it presents an unusual aspect by being beset with small nodules which, if examined under the microscope, prove to be more or less entirely filled with Bacteria of the species *Bacillus*—or "*Rhizobium*"—*radicicola*. In Egypt, so far as I have found, the roots of lupins do not seem to develop such nodules, whereas quite corresponding changes due to the same, or to nearly related Bacteria, are of frequent occurrence in the roots of the Egyptian clover (برسيم). The Bacteria, present perhaps in every soil, as soon as they come into contact with a young root of a suitable host-plant penetrate into it by destroying the cellulose-walls of the cells, and then multiply considerably, thereby inducing the plant to form the nodules. But, while, on the one hand, depriving the host-plant of some part of its proteid-matter, they, on the other, supply it with the nitrates they produce from the nitrogen of the air which we know permeates almost every soil in a fairly large proportion. Thus indeed each partner, while it takes something useful from the other, gives something useful in return —the distinctive feature of "Symbiosis". The phenomenon, by the way, is widely spread in the world of organisms; in the case of the *Leguminosae* and their Bacteria, it also has practical value for Man. For if the roots with their nodules are left to decompose in a soil after the cutting of the plants, the relatively considerable amount of nitrates contained in them becomes available for other plants which may subsequently be grown in the same soil. According to calculations made, lupins, for instance, on a feddan (=about 4,200 square metres) of land, by the help of the Bacteria are able to bind about eighty kilogrammes of nitrogen, that is an amount for which otherwise on an average 12,000 kilogrammes of ordinary dung would have been required.

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* From σύν—together, and βιόω—see p. 2.

Certain important modifications also exist with regard to the **respiration of the bacteria.** All of course respire, and for the purpose require oxygen. While, however, the majority take it from the air, and can respire solely in this way, others are capable of abstracting it from the chemical compounds in their surrounding. We technically call the former category "**Aerobic**"*, the latter "**Anaerobic**"; but certain very interesting differences still exist with regard to the degree of the anaerobic habits. There are the so-called "**Facultative**" **Anaerobes** which in the main respire in the ordinary way and only in cases of emergency themselves manufacture oxygen. They gradually pass over into the "**Obligate**", or "**Strict**" **Anaerobes** which have so fully adapted themselves to the anaerobic habits that the mere contact with gaseous oxygen prevents them from thriving. The Tetanus-bacillus, among the parasitic Bacteria, the *Bacterium butyricum*, among the saprophytic, are well-known instances of such a strict anaerobic mode of life.

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* From the Greek ἀήρ (Latin: aër) — air and βιόω (p. 2); for "Anaerobic" see note * on p. 4.

It may here be added in passing that similar anaerobic habits, either facultative or obligate, are also found in a number of other lower plants, among which there is the Yeast-Fungus.

CHAPTER XI.

On the Classification and Structure of the Higher Plants.

I now have to make you somewhat acquainted with the internal organisation of the higher plants. Before doing so I find it desirable to say a few explanatory words about their **external shape** which so markedly diverges from that of the higher animals. It is worthy of note, in the first place, that this dissimilarity does not appear, or is merely hinted at, in the unicellular representatives of both kingdoms. Indeed, if we contemplate a *Spirogyra*-cell and a *Gregarina*, or the zoospore of an alga and a free-swimming Infusorium, their difference in shape is anything but striking, and becomes altogether nil if we extend our comparison to the members of the Class Flagellata which hold that singular intermediate position between animals and plants mentioned on pages 258 and 262. Considering these facts it becomes probable that the striking difference we observe between the general shape of a higher animal and that of a higher plant is the result of a gradual specialisation similar to that we found on a previous occasion in the animal and vegetable metabolisms (p. 278). It even appears that the former specialisation is a mere consequence of the latter; one thing at any rate is certain, namely, that the peculiarities in the shape, of the higher animals on the one hand and those of the higher plants on the other, become comprehensible if we consider them each as an adaptation to the respective metabolism.

The animals we know feed on organic matter which is compact and by being broken up releases the energy stored in it. A large part of this energy is converted into movements, for which purpose it is indispensable that the animal body should possess a certain regular shape without unnecessary external appendages. So all the organs concerned in the treatment of the food and the utilisation of the power gained from it are collected within the body, and any large surfaces when required for absorption or excretion are found on the inside of outwardly compact organs (compare here what was said about the structure of the intestine on page 30, and what will be said about lungs and kidneys on pages 450 and 460ff).

The plants feed on inorganic materials which require energy to be built up into organic substance; hence the absence of voluntary movements, a fact which makes the plants free, so to speak, to assume any shape that seems suitable. The materials they feed on are not compact but distributed, in a very diluted condition, partly in the air and partly in the soil. We have already seen that the latter circumstance leads to the separation of the vegetable body into shoot and root (p. 266), while the dilution of the food-materials necessitates large surfaces for the absorption of sufficient quantities. Both shoot and root are indeed intensely ramified and, as the shape is not restricted by other exigencies, unfold all their surfaces outwardly. Since, finally, the plants derive the energy for living and growing, not from within, but from the light outside, they must seek this and for this purpose arrange their leaves in such a way that they are hit by the light as fully as possible or desirable.

The external characters here enumerated are in principle common to all higher plants; apart from that, however, these vary in structural details and life-history within wide limits. We use the differences in question for establishing a scientific classification of the plants, taking as basis their natural relationship, in a similar way as we did in the case of the animals (see pp. 224ff). As a consequence of this intimate connection between structure and classification, a summary of the latter will simultaneously be a description of the chief structural and developmental types which occur among the plants, and may accordingly serve as a convenient introduction to our actual subject.

The whole vegetable kingdom falls into the two large sub-kingdoms of the "**Cryptogams**" and the "**Phanerogams**" *, so called because the former have their reproductive organs "hidden", the latter "apparent". I must here mention in anticipation that the sexual organs of the higher plants are situated in their flowers; you know from daily experience that these are very conspicuous in many herbs, shrubs, and trees; on the other hand, we found nothing like them in the various lower plants we studied in the preceding pages, and would look for flowers equally in vain in plants like the "Mosses" and the "Ferns" (representatives of which are, in this country, met with only locally in moist and shady places, such as e.g. the brickwork of old wells, etc.). Notwithstanding, all these plants, with the exceptions repeatedly mentioned (e.g. p. 124), have sexual organs, or sexual stages, by which they propagate their race; but the respective parts are only slightly apparent to the casual observer and hence the name Cryptogams. Bacteria, Algae, Fungi, Sea-weeds, Mosses, Ferns, and others are representatives of this sub-kingdom. The bodies by which they reproduce themselves are of the kind which on page 248 we characterised as spores, i.e.

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* From κρυπτός—hidden, concealed and φανερός—visible, open; for γαμέω—see note *, p. 136..

they consist of a **single** cell (either free or enclosed in a shell) which may, or may not, go through a period of rest before it develops further; but when once it has begun this development accomplishes it **without** any intercurrent **interruption**. Owing to this reproduction by spores, which is common to **all** Cryptogams, these are also called "Spore-Plants", or "**Sporophytes**" *.

The Phanerogams, on the other hand, besides their having conspicuous sexual organs in the flowers, propagate their race by seeds. I have already pointed out on page 249 that these differ from the spores chiefly by their containing a young plant comparable to the animal embryo. This "vegetable embryo" **also** originates from a single cell, namely the fertilised egg-cell; since, however, every seed, before sprouting, i.e. continuing its development, undergoes a more or less long period of rest, it follows that, in the Phanerogams, the whole development from the unicellular stage into the full-grown plant is **regularly interrupted** during, and by, the seed-stage. This is another distinction between the Cryptogams and the Phanerogams which latter, owing to their reproduction by seeds, are also called "Seed-Plants" or "**Spermophytes**".

The Phanerogams, though all producing seeds, do so in very different ways which, in their turn, depend upon differences in the structure of the reproductive organs. One such difference, of lesser importance, is given in the **distribution of the sexes**. In the greater number of the existing Phanerogams each flower contains male as well as female organs; on page 153 we saw that animals presenting this peculiarity are termed **hermaphroditic**; we use the same name for designating the type of flower under consideration. In the remaining Phanerogams, the individual flower is "**unisexual**", i.e. it contains either male or female organs and is therefore a "male flower" or a "female flower". Among the plants with such unisexual flowers there occurs an interesting additional difference inasmuch as, in certain groups of natural relatives, both types are found on one and the same plant, while in other groups they are even distributed onto separate individuals of the species. In the former case, we accordingly still have hermaphroditic plants, with however, unisexual, i.e. male and female, flowers; in the latter case, we have unisexual, i.e. male or female plants, each with flowers of one sex exclusively. Here, therefore, and just as in the unisexual animals, each species is represented by two varieties of individuals, male and female, which may, or may not, differ in their outward appearance; thus showing, in the former case, what we know as "sexual dimorphism" (p. 166). The fact of the sexual organs being thus lodged, as it were, each in a separate "house", has led to the designation "**dioecious**"[*] plants, in contrast to which those carrying male and female flowers on the same shoot are called "**monoecious**"[†]. Special examples of both types will be mentioned in their place.

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* From φύτον — see note *, p. 280.

A difference more fundamental than the distribution of the sexes is given in the **circumstances under which the seeds are formed.** Without going into great details, I will here only state that there is one Class in which the seeds are simply developed on the surface of certain (more or less specially transformed) leaves, and are thus fully exposed to view, or merely covered from without by the respective leaves, from beginning to end. Owing to this fact of the seeds being "naked", the respective plants are combined under the name "**Gymnosperms**" *. Their representatives form a large proportion of the "Flora" † of earlier periods of the earth, but are well-known as they are at present abundantly found in carbonised or petrified conditions (compare here pp. 272 and 396). The most common and most widely spread living members of the Class are the "**Conifers**", so called because they form their seeds in characteristic cone-shaped aggregates, the "pine-cones". In contradistinction from the ordinary "foliage"-trees (i.e. trees with leaves) they may also be called "needle-trees", because their leaves represent shorther or longer, fairly hard needles. Conifers do not naturally occur in Egypt, though several species are not infrequently cultivated in gardens (e.g. *Pinus strobus*, the Weymouth-pine of North America, *Araucaria imbricata* and others from South America, etc.). You probably also know by sight *Abies alba* and *Picea excelsa*, the two species which every winter are imported into this country as "Christmas trees". The conifers count among their number the most powerful plants known; you have perhaps heard of the "giant-trees" (*Sequoia gigantea*) from the mountains of California, which attain a height of 100 metres with a diameter at the base of twelve metres and are, next to some foliage-trees, as e.g. the "fever-trees" of Australia (*Eucalyptus amygdalina*) which attain 150 metres by a diameter of ten metres, the largest trees actually in existence. Many Conifers are of great practical importance, for they supply the largest proportion of the wood used by man for technical or household purposes; they in addition are very rich in resins from which turpentine, varnishes, etc., are made.

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[*] Greek, from δίς—twice, double and οἶκος (or οἰκία)—house, habitation, living-place.

[†] From μόνος—see note †, p. 133, and οἶκος.

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* From γυμνός—naked.

† "Fauna" and "Flora" are two technical collective terms, frequently used in biological and geographical sciences to designate, the former all animal organisms, the latter all vegetable organisms, living within a certain region, or having lived in a certain geological epoch, of the earth. Thus, if we want to enclose in one expression the whole community of animals inhabiting this country we speak of the "Fauna" of Egypt"; and if we speak, as above, of the "Flora of an earlier epoch" we want to circumscribe by the term all the plants we know, and may still come to know, from that epoch.

At variance from the Gymnosperms, the remaining Phanerogams are "**Angiosperms**"*, i.e. they form their seeds no longer on the surface of certain leaves, and more or less freely exposed to view, but inside a particular part of the flower which completely envelopes them on all sides. We shall return to this structure in some more detail when speaking of the reproduction of the plants (page 369). The consequence of this position of the seeds is that they are hidden from view up to the moment of their being discharged from the plant in the natural course of events. You may get an idea of these conditions if you think of the seeds in the dates (بلح), the oranges (برتقال), melons (بطيخ), and so on. The Angiosperms represent by far the greatest proportion of the Phanerogams: the grasses, herbs, shrubs, and nearly all foliage trees belonging to them. Among themselves, they fall into two large Sub-classes, viz. the "**Monocotyledons**" and the "**Dicotyledons**".

In the streets of this town, date-stones are often thrown away; in certain protected places, e.g. in the depressions made round the street-trees for watering them, these seeds find an opportunity to sprout. The same, among others, frequently happens to wheat- and barley-grains dropped from the fodder of horses, etc. If you observe these sprouting seeds, you will notice, and perhaps have already noticed, that the young plants first emerge from the earth with **one** sword-like leaf directed upwards. If, on the other hand, you allow a lupin (ترمس) or a cotton-seed to germinate, you will see that the young plants from the first show **two** broad leaves placed about horizontally and opposite each other. You here have the chief and most easily observable difference between the two Sub-classes above introduced by their names which refer to the phenomena described; for the first leaves of the plants, already preformed in the seeds and, as a rule, differing in shape from the later ordinary leaves, are distinguished as "**Cotyledons**" *.

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* From ἄγγος, or ἀγγεῖον—vessel, receptacle.

Date-palm and wheat, in fact all the various palms and the many species of "grasses", are, perhaps, the most typical and certainly the most commonly known representatives of the Monocotyledons; others, of greater or lesser practical importance, are the Onions (بصل), Asparagus (كشك الماز), the Aloës and Agaves (صبار). The flowers of the Monocotyledons are as a rule hermaphroditic, but certain exceptions occur. Thus you know that the Maize (ذره شامى), for instance, produces separate male and female flowers on the same stem, while the date-palm (نخلة) is even diœcious.

The Dicotyledons comprise the rest of the Angiosperms. As, in their case, the structure of the seeds, and the development of the young plants from these, are both easy to observe and to comprehend, I will here shortly sketch them in completion of the disconnected details mentioned on pages 249, 300, 319 and 333. If we examine a seed of e.g. a lupin (ترمس), or a bean (فول), in their ordinary condition, we find them to be dry and fairly hard, with a more or less wrinkled surface. If we place them in water or in a basin with some moistened filter-paper at the bottom, they will soon imbibe the fluid and swell (just as they do when sown in the soil), their surface becoming smooth and even. If we dissect one in this condition we find, within the (coloured or uncoloured) skin, a whitish mass which, along the plane of the largest circumference of the seed, easily breaks up into two halves. These are the cotyledons; on looking more closely, we will see that they are not entirely separated, but, at a place near the margin and near one end of the seed, both cohere with a small spindle-shaped body which thus connects them with each other, in a somewhat similar way, as, e.g. the body of a butterfly (أبو دقيق) connects the wings of either side. The small spindle-shaped body is the embryo proper, and inwardly consists of three (outwardly not recognisable) portions, the middle one of which carries the cotyledons, while the two terminal ones are, the anterior one the primordium (p. 156, note †) of the shoot, the posterior one the primordium of the root, of the definitive plant. If we keep these seeds under adequate conditions we will be able to follow their further development known under the names of

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* Κοτυληδών, in Greek, originally means something hollow, and refers to the first leaves, probably in so far as these, in the seed, also have a somewhat hollow, mainly spoon-like shape.

Germination or Sprouting. It is the primordium of the root which begins to grow first, and to emerge from the seed, after bursting the skin at the respective place. Under natural conditions, i.e. the seed being placed in earth, the root pushes on perpendicularly downwards, and by increasing in length soon gets firm hold in the soil. While this is accomplished the middle part of the embryo also commences to lengthen;

since, however, its two ends are fastened, the posterior end by the root, the anterior end by the bulky cotyledons, it is, as it grows, forced to bend, and does so after the fashion of a horseshoe. Hence the curious fact that the first part of the young plant which makes its appearance above ground usually has the shape of a loop represented by the lengthened middle-piece of the embryo. Not until this part has gained a certain strength does it become enabled to stretch, thereby pulling the cotyledons, first out of the seed-skin, and subsequently out of the earth. When this takes place they are still whitish in colour and lie flat against one another; but while the stalk continues to straighten itself they gradually open and eventually assume the horizontal position opposite each other (see above, p. 323), while at the same time turning green. Thus, if we carefully unearth a perfectly stretched seedling, we find it to consist of a fairly long and stout root which may already have developed some lateral branches, and is derived from the posterior portion of the original embryo. It anteriorly passes into a simple stalk—the middle-piece of the original embryo—which at its upper end carries the two cotyledons now transformed into perfect leaves of a simple shape. Between them we discover, on close inspection, a small bud—the anterior portion of the original embryo—which thus far has remained almost inactive, but subsequently develops into the plant proper.

This is, in its main outlines, the way in which a dicotyledonous plant develops from the seed. The process varies of course in the different representatives of the group; I may here mention in particular that, among others, in the bean (فول) the cotyledons are not unfolded above ground, but remain in the earth, the developing shoot being the first part of the plant which appears. Other deviations cannot here be entered upon.

The full-grown Dicotyledons show among themselves a great variety of structural types and are accordingly classified into a number of Orders, Families, etc., upon which I cannot here enter. Their distinctive characters are chiefly afforded by modifications in the arrangement of the reproductive organs. The flowers of the Dicotyledons indeed present to the observer a most marvellous variety of shapes and colours, passing from simple and comparatively regular forms over into others of singularly complicated and irregular composition. The flowers of the various herbs, shrubs, and trees of this country, if you compare them attentively, will supply ample evidence of the truth of this statement.

After these introductory remarks I proceed to a brief account of the **internal structure** of the higher plants. Owing to the many variations they show, both in general arrangement and particulars, it is of course quite impossible to go much into details, or to mention all the different modifications an organ or a tissue may present. What I will attempt is to show you how the vegetable body is built up in general, and how the structure of its various parts tallies with the particular vital functions of these parts.

1.—CELLS.

Like the higher animals, the higher plants have their bodies composed of **cells.** We have already convinced ourselves that with regard to the essential features of structure and vital activity there is no difference between the animal and the vegetable cell; and yet, in ninety-nine cases out of a hundred, a single glance will suffice to practically tell the one from the other by their general appearance. The fact is due to certain secondary peculiarities of the vegetable cell. The most important of these is the presence of the sharply defined cellulose-**wall** already mentioned (p. 241). Even if this is quite thin and little apparent (see, e.g. Fig. 5, Pl. XIX) it has a certain rigidity which increases in the measure as the wall becomes thicker. Hence the definite, unchangeable shape of the vegetable cell, which we already noticed in the unicellular plants, and find still more emphasised in the higher, where the cells unite to form tissues. As a matter of fact, any vegetable tissue, under the microscope, at once strikes the observer by the **definite shape** of its constituent cells, and, as a consequence thereof, by the **regularity of their arrangement** (compare here, among others, the figures of Pl. XIX); two pecularities which to the same degree are not met with in any animal tissue.

A second, though less general property of the vegetable cell is the strong vacuolisation of its protoplasm. We have already touched upon this characteristic on page 244, where it was stated that the production of cell-sap may go so far as to reduce the cytoplasm proper to a thin film—the primordial utricle—lining the cell-wall and enclosing at some place the more or less flattened nucleus. This metamorphosed state may be described as almost typical of the fully developed and living vegetable cells, and readily separates them from the animal. I would, however, emphasise the words fully developed and living; for young cells, as we shall see in due time, are not yet changed in this way (Fig. 5, Pl. XIX) and certain others normally die in the course of the plant's life; many plants, indeed, have their bodies quite regularly made up of living and dead cells. In these latter, the cell-sap alone remains, or even this may gradually disappear and be replaced by air. You are familiar with the fact that many plants, or parts of plants, even if perfectly fresh, float on the surface of water; it is the air contained in certain of their cells which keeps them afloat. After the disappearance of the living contents the cell-walls remain the only constituents of a tissue and their regular shape and arrangement then come fully into evidence. On seeing such a tissue in a thin section one readily comprehends the name " cell " given to its constituent parts by the first observers (p. 45).

To these general characters of vegetable cells and tissues several details must be added. Beginning with the **cell-wall**, this is very thin in all young cells, but becomes more or less thickened in old. This growth in thickness is due to **apposition** of new substance to its inner surface. We here therefore have an example of this form of growth among organisms, as alluded to on page 15. The new layers, as they often are somewhat different in refractive power, may give the whole wall a distinctly **stratified** aspect (Fig. 3, Pl. XVII). In many cases the thickening is equal all round the circumference of the cell; in others it is not, and the wall then exhibits particular **markings** produced by the optical differences between the thickened and non-thickened areas. To mention some details, there are cells in which these markings present themselves as so-called "**Pits**". Under a low power of the microscope these appear as simple small holes in the cell-walls, or, in other words, as fine canals piercing them (Fig. 1, Pl. XVII). On employing a higher enlargement one sees that the single canal does not extend through the whole wall but ends at its thin, original, i.e. outermost layer which thus appears a fine membrane closing the pit. In every isolated cell this "**Closing**

Membrane" accordingly lies at the outer end of the canal; since, however, in every two neighbouring cells, provided that they possess pits of the same kind, these latter exactly coincide the closing membranes come to lie in the middle of the entire canals. This is shown under a high enlargement in Figure 1, Plate XVII, where the cell-wall directed towards the observer is cut so as to exhibit the pits in longitudinal section and with the closing membranes in their middle.

The shape of the pits varies. Generally they are circular or slightly oval as in the figure just referred to; often they are very delicate and narrow (Figs. 4, 5, Pl. XVII), and in the case of very thick-walled cells they may be ramified (Fig. 3, Pl. XVII). Of particular forms which exist, I may still mention the "**Bordered Pits**" distinguished by a regular double outline of their openings (Fig. 2a, Pl. XVII). The appearance is brought about by a strongly conical shape of the cavity, which comes into view in longitudinal sections of the pits (Fig. 2b); the closing membrane lies not in the middle, as usual, but is pressed against one of the openings (*cM*, Fig. 2b).

In the case of the pits the non-thickened areas of the cell-wall appear as special structures on a generally thickened background; in other cells (chiefly of the vascular system), we find reversed conditions inasmuch as the cell-walls remain in the main thin, while certain comparatively small portions only become thickened and thereby mark themselves as particular structures. They are chiefly linear in shape and sometimes form isolated rings running more or less parallel and at varying distances round the periphery of the cells (**annular** markings; Fig. 7, Pl. XVII); sometimes they arrange themselves in regular spiral lines (**spiral** markings; Fig. 8, Pl. XVII). An intermediary position, so to speak, between these markings and the ordinary pits is held by the " **scalariform** " and " **reticulate** " markings. In both, the thickened and the non-thickened areas of the cell-wall are about equal in proportion, and the former represent, in the first case, fairly regular, parallel ridges at right angles to the long axes of the cells (Fig. 10, Pl. XVII), thus imitating to some extent the aspect of a stair (whence the name scalariform *) ; in the other case, they appear as a network of irregularly anastomosing ridges (whence the name reticulate ; Fig. 9, Pl. XVII).

Chemically, as you will remember, the cell-wall is chiefly made up of cellulose (p. 241). Exceptions to this rule are found in cells which have particular functions in the household of the plant. The two most important substantial changes which the walls may undergo in adaptation to these special functions are " **Lignification** " †, i.e. transformation of the cellulose into wood, and " **Suberisation** " ‡, i.e. transformation of the cellulose into cork. Wood and cork differ from cellulose both physically and in their chemical constitution. In the former respect, wood is considerably harder than cellulose ; lignified walls, as a consequence, are found in all those cells which have the mechanical function of rendering the vegetable body stable. The more numerous such lignified cells are in a certain part the harder it becomes ; you know for instance that it is much easier to break the stalk of a bean plant than it is to break an equally thick twig of a tree ; the reason is that the latter is lignified to a great proportion while the former is not. The other substance, cork, is remarkable by the resistance it offers to the passage of water; we accordingly find cells with suberised walls at places where an evaporation should be prevented. As every evaporation-process must needs take place through the surface of the plant, we logically have to look for cells with suberised walls there. Our ordinary bottle-corks, as a matter of fact, come from certain trees in which such cells form a thick coat round the stem. These corks also clearly exemplify the chief property of the substance they consist of; for, however long we may immerse one in water, it will not imbibe it, in contradistinction to wood which gradually, though slowly, becomes soaked with it.

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* From the Latin "scalae"—stair, ladder.

† From the Latin "lignum"—wood.

‡ From the Latin "suber"—cork.

The exact chemical constitutions of wood and cork are not yet satisfactorily settled, though we have certain characteristic reactions of both. Chloroiodide of zinc, among others, which to the original cellulose gives the blue tint, with wood only produces a yellow and with cork a yellow-brown colour.

The aim of rendering a cell-wall impervious to water is in certain cells also attained by a process called "**Cutinisation**"*. It of course also concerns superficially situated cells, but in contrast to suberisation (which otherwise it much resembles) remains limited to that part of the cell-wall which is in actual contact with the outer world (as, e.g. the outer surfaces of the leaves; see p. 336).

The **cytoplasm** of the vegetable cell, besides the cell-sap, often encloses special structures, some of which must here be shortly dealt with because they play an important general part in the life of the plant. We begin with the **chromatophores**. It has already been stated (p. 243) that these consist of a proteid ground-substance permeated with chlorophyll, and in the cells of the higher plants represent small lentil-shaped bodies scattered in considerable number in the primordial utricle. An interesting phenomenon is that the chromatophores are capable of shifting their position, not of course actively, but owing to movements of the cytoplasm in which they are suspended, and do so in connection with changes in the intensity of the light. For, strange to say, though light is indispensable for the chromatophores to assimilate carbon, there is evidently a limit, beyond which its intensity seems to become unpleasant to the plant (see here p. 263). It is at any rate a fact that the chromatophores in intense sunlight withdraw from the surface of the cells and take up a position, in which they turn their edges, i.e. their smallest surfaces› to the source of light, while under ordinary circumstances, i.e. in diffuse day-light, they lie along the cell-surfaces and allow themselves to be fully hit by the incoming rays. The consequence of this different position of the chromatophores becomes occasionally perceptible to the naked eye ; for if you pay attention to the fact you may notice that certain plants in intense sunlight exhibit a distinctly brighter shade of green than they do under a clouded sky.

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* From the Latin "cutis"—skin, especially its thinner and softer modifications.

All the chromatophores of a green plant are derived from those already present in the egg-cell, but do not of course develop their colour previous to their coming into contact with light (see, e.g. the cotyledons. p. 325). In the growing cells they multiply by division.

Starch is another substance which occurs with great frequency in vegetable cells. We have already seen that it first arises in the chromatophores in the shape of small irregular grains which again disappear at night owing to dissolution under concomitant transformation into sugars.. . This starch, as it is the direct result of the assimilatory activity of the plant is specialised by the term "**Assimilation-Starch**", but is not the only form in which starch occurs in the plant.

It is a well-known fact that the animal organism, during periods of ample food-supply, absorbs more than it actually requires; elaborating the surplus into fats and depositing these as a kind of food-store to draw upon in periods when food is scarce, or cannot for some reason be taken at all (see e.g. pp. 16, 213). We have further seen that many animals more or less abundantly provide their eggs with yolk, a substance which, despite its different physical properties, yet biologically exactly corresponds to the fats inasmuch as it represents a condensed food-substance to serve the developing young until this becomes able to look for its nutriment itself. What yolk and fat are to the animals, starch (and various oils which are sometimes formed in place of, or in addition to, starch) are to the plants. The assimilation-starch, after its removal from the leaves, is not entirely used up in growth and work, but a certain amount is again deposited as solid grains in various parts, to be used in times of need. You know, for instance, that many trees at regular intervals drop their leaves and remain bare until after some time new leaves appear. Such bare trees, owing to the absence of chlorophyll, cannot of course elaborate new body-substance, and yet they manufacture it abundantly when forming the new leaves. They are enabled to do so with the help of the starch which had been stored for the purpose in certain tissues of the stem. Starch-grains are further plentifully deposited in the seeds and certain bodies which also serve the purpose of propagating the race (as e.g. underground tubers, etc.). This starch, for the young developing plant, has absolutely the same significance as has the yolk for the growing animal embryo, and the biological parallel which exists between the two substances is complete.

The starch stored after the fashion described, as it has not been manufactured at the places where it is actually found, and also has a purpose of its own, is differentiated from the assimilation-starch as "**Reserve-Starch**", a term which you will understand without further explanation. The grains of the reserve-starch like those of the other variety are formed in small protoplasmic bodies in every respect similar to the chromatophores, with the sole exception that they are unprovided with chlorophyll, and practically need none. As the starch which they, so to speak, only precipitate from its dissolved condition is not again removed for some time the grains grow continually by apposition of fresh material and may occasionally reach a size large enough to make them visible to the naked eye. Their most marked optical characteristic is a distinct stratification (Fig. 11a, Pl. XVII) due to differences in the density of the successively deposited layers. This striation is sometimes concentric, oftener excentric. Some grains have one centre, others have more. If, in the latter case, these become surrounded by some common layers, the grains are termed "half-compound" (Fig. 11b); if there are no such layers the grains are "compound". Usually only two or three single grains coalesce to form a compound grain, whereas those of oats and rice, among others, regularly consist of one to several dozens of single grains (Fig. 11c).

Besides (or in place of) starch, the vegetable cells may elaborate a host of other substances, in part as secretions, in part as excretions (compare p. 39). Some of these, as e.g. the fats and fatty oils (already alluded to above), ethereal oils, resins, gums, guttapercha, indiarubber, and others have gained so great a technical importance that the plants producing them are artificially cultivated for obtaining their products. Our time is, however, too limited to follow this subject up any further.

2.—TISSUES.

We now turn to a short consideration of the vegetable **tissues.** In the description of the animal tissues (p. 38f) it was pointed out that the cells composing each are among themselves alike in structure and function, while different tissues, or even varieties of the same tissue, are distinguishable from one another by the particular shape of their cells. The same may in the main be said of the vegetable tissues, although the regular shape of all vegetable cells and the reduction of their living contents may in individual cases render the distinction by the eye alone somewhat difficult.

The number of independent tissues existing in the body of the plant is inferior to that we find in the animals, for in accordance with the absence of voluntary movements the plants possess neither muscles nor nerves, that is, no "animal organs" (p. 31). Their tissues may be classed into four chief varieties. There is (1) the **Epidermal** or **Tegumentary Tissue** which exactly corresponds to the epithelial tissue of the animals; there is (2) the **Parenchyma** or **Ground-Tissue** which presents numerous analogies to the connective tissue of the animals; there is (3) the **Vascular-Bundle-Tissue** which, in the biological though not the histological sense, offers a parallel to the circulatory system of the animals; and there is (4) the **Embryonic** or **Meristem-Tissue** which has no exact counterpart in the animals—not, at any rate, in adult individuals. The structure of these tissues always clearly shows their adaptation to their particular functions.

The **epidermal tissue** has to cover the plant and to protect it against harmful influences from outside. It is accordingly found all over the surface of the body, usually in the shape of a single layer of cells closely applied to one another. If seen from the surface the cells present irregularly wavy outlines (Fig. 4, Pl. XVIII) while in cross-section they give the impression of an ordinary cubic or rectangular shape (*Ep* in Figs. 3, Pl. XVIII 1b, 3b, Pl. XIX). The epidermal cells, as a rule, do not take part in the assimilating process and hence are destitute of chlorophyll; but there are exceptions. The cytoplasm is very much reduced, the chief content being water. Among the damages the plant may receive from outside the one most likely to occur is undue loss of fluid by evaporation. Wherever this is possible, that is, on all parts exposed to the air, the outer surface of the epidermis-cells becomes thickened, cutinised, and additionally covered with a thin, resistant pellicule, called the "cuticle" (see *Cu* in Fig. 5, Pl. XVIII). In parts not liable to evaporation (e.g. roots, submersed leaves) these changes are little marked or entirely absent, whereas plants specially adapted to a life in warm, dry climates need them in an intensified degree, and hence often strike the observer by a strange hardness of their leaves which is brought about by an excessive thickening of the cell-walls in their epidermis. The flora of Egypt supplies numerous examples of such hard-leaved plants.

The stem in many trees grows considerably after it has first been formed and its epidermis consequently has to cover a continually increasing surface. It might comply with this demand by repeated divisions of its cells; as a rule, however, the epidermis-cells, as all vegetable (and animal) cells, lose the power of division with the assumption of their definitive shape. Under such circumstances, the epidermis, during the subsequent so-called Secondary Growth (see p. 348), can only give way by a mechanical distension of its cells, which may lead to a bursting and eventual total destruction. The original and true epidermis is then replaced by one or more layers of cells which originate from the underlying tissue and have their walls perfectly suberised, their insides being filled with air. In this way the "**Bark**" of the trees arises.

Many plants have their bodies, or parts of these, covered with **Hairs** which are produced by the epidermis (see *H* in Fig. 3, Pl. XVIII). Apart from this, they vary a good deal in details; thus, the individual hair may be one metamorphosed epidermal cell, the living content of which dies and is replaced by air when the hair is fully developed. The cotton-seeds, among others, on their outer surface develop hairs of this description, which stand out from other similar hairs by their unusual length, and, when detached, represent the cotton-"wool". Under the microscope (Fig. 6, Pl. XVIII) they appear as colourless, thin-walled, hollow, and slightly twisted fibres, differing thus clearly from both the silk-threads (p. 188) and the flax-fibres (p. 347). In numerous cases, the vegetable hairs consist of many cells, the contents of which remain alive and elaborate various substances of use to the plant. Some of these have a strong smell (as in the Mint, Arabic : نعناع, the Rosemary, Arabic : حصى لبان etc.); others have the property of irritating (as in the Nettle, Arabic : قراص,) etc.; the proteolytic ferment of the insectivorous plants mentioned on page 287 is also produced by such hairs.

The formation of a resistant and impervious coat all over the surface, while it is of undoubted advantage to the plant in some respect, is of as undoubted disadvantage in another. We know that a large and important proportion of the raw food-materials is derived from the air and can only be absorbed by osmosis, i.e. through the unbroken cell-walls; cutinised or suberised cell-walls, however, have just the function of preventing osmosis. The plant has found the way out of this dilemma by leaving, wherever it is necessary, countless small openings in its epidermis, the so-called "**Stomata**" which, by a particular mechanism, can be opened and closed and, moreover, inside the body, communicate with cavities the boundary-cells of which have no specially transformed walls and thus can absorb gases (*Sto* in Fig. 3, Pl. XVIII). We shall describe the structure of the stomata when dealing with the leaves (p. 365); at this place, I will only point out that the plant, by opening them, brings the inner, thin-walled cells into the necessary contact with the atmosphere, by closing them shuts itself off from the outer world. In this way it can feed and respire, or protect itself against excessive evaporation, as circumstances require.

The **vascular-bundle-tissue**, as already hinted, corresponds to the circulatory system of the animals anatomically and biologically, but differs from it histologically. For, while in the animals more or less flattened cells join together to form the walls of the vessels and thus encircle their cavities, the vessels of the plants consist of hollow cells, the walls of which turn into the vascular walls, while the contents disappear and thereby cause the formation of the cavity. It is brought about in this way that the individual vessel remains of about the same diameter throughout the plant, and that the demand for any increased capacity which in the animals is realised by a widening of the vessels, can in the plants only be complied with by an addition of new vessels to those already existing. This is perhaps the reason why the vegetable vessels, with the exception of their terminal portions, always occur in **bundles**.

The individual vessel consists of a single row of elongated, prismatical cells placed end to end. With regard to all other particulars there are variations which in the first place depend on the function of the vessels. I here recall to your minds what was said on page 267 of the two currents in the vascular system of the plants; the tubes through which each runs are characteristically different from those of the other.

The **downward current** conveying the **proteid-matter** elaborated in the leaves is restricted to the "**Sieve-Tubes**" (Fig. 6, Pl. XVII). These consist of cells which within their thin walls still contain living protoplasm, but have lost their nuclei. The partition-walls between every two consecutive cells, placed sometimes about perpendicularly (Fig. 6a) sometimes more or less obliquely to their long axes (Fig. 6b), do not disappear, but become pierced by numerous small canals, which are either irregularly scattered over the whole surface of the partition-wall (seen in optical longitudinal section in Fig. 6a), or collected into a number of distinct groups separated from one another by non-perforated areas (seen in surface-view in Fig. 6c). These perforated plates, as they copy to some extent the picture of a sieve, are called "**Sieve-Plates**"; they represent the most characteristic parts of the whole tubes and have suggested their particular name. The protoplasmic contents of the cells extend into the canals of the sieve-plates and through them communicate with the contents of the neighbouring cells, a continuous road of protoplasm being thus created for the conveyance of the proteid-matter all over the length of the sieve-tubes.

The **upward current**, as we have seen, conducts **water and salt-solutions** from the roots to the leaves and runs in tubes which we call "**Tracheæ**". They differ from the sieve-tubes generally by the following characters: (1) their more considerable width; (2) their lignified walls; (3) the absence of any living content; (4) the more or less complete disappearance of the partition walls between consecutive cells. Under these conditions, the tracheæ become continuous empty canals with resistant walls such as are practically required for the conduction of fluids. Among themselves, they show differences bearing on details in the conformation of the walls which are always thickened, but in various ways. The chief varieties which exist have been described on pages 328ff, and we accordingly distinguish "**dotted**" **vessels** (either with simple ordinary, or with bordered pits), "**annular**", "**spiral**", "**reticulate**", and "**scalariform**" **vessels** (Figs. 7-10, Pl. XVII).

The **ground-tissue** or "parenchyma"* makes up the main bulk of the vegetable body, in other words, it fills the space left free within the skin by the vascular bundles. I have above (p. 335) drawn a parallel between it and the connective tissue of the animals, and my reason for doing so is that both tissues, besides pushing in between, that is, connecting, other tissues, also fall into a number of very distinct varieties which result from an adaptation to particular additional functions. The latter naturally differ according to circumstances and in the various natural groups of organisms; but the **fastening** the whole body together and the **storing** of certain substances everywhere rank among the foremost, because of their almost universal necessity. Thus, you know from animal histology that the adipose or fat-tissue, though connective in nature, has the additional function of storing a surplus of elaborated food-material; that elastic, cartilagineous, and bone-tissues are equally varieties of the connective system, but have the additional function of rendering certain parts resistant, the elastic tissue to traction, the two other varieties, each in a somewhat modified way (see p. 38f), to pressure. The same two functions, besides others, play an important part in the vegetable body and cause the ground-tissue to undergo adequate modifications.

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* This term, derived from the Greek ἔγχυμα—some material poured into a receptacle, is in Biology generally used for tissues "poured in", so to speak, between the organs of the body.

In their original condition, the cells of the ground-tissue have an almost spherical shape with thin walls and a living though very inconspicuous content. Owing to mutual pressure, however, they practically always assume an angular surface; retaining, in the central portions of the plant, a simply polyhedric form like e.g. the bubbles in the foam of soap, while in the peripheral portions, especially of stretched parts like petioles, stems, and roots, they become prismatic. In the first-named shape the cells not infrequently only contain air; usually however, they serve the purpose of storing and the respective variety of the ground-tissue is then conveniently differentiated as "**Storage-Tissue**". Its cells may be filled with liquids, either water, or fluid food-materials such as solutions of sugar and proteids. In other cases they are stocked with solid nutritive substance in the form of starch; finally, several of these bodies (or others) may occur together in the same cells. In order to give you an approximate idea of the occurrence of this tissue, of the influence its presence may exercise on the shape of the parts containing it, and of the biological significance it has for the respective plants, I will here quote a few well-known examples.

In this country we have quite an assortment of plants with remarkably "**fleshy**" or "**succulent**"*

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* From the Latin "succus"—sap, juice.

leaves and **stems**; succulent leaves, for instance, are found in the Aloës (Arabic صبار) and Agaves (this latter of American origin); succulent stems in the various Cactuses, among them *Opuntia ficus indica* (Arabic تين أبو شوك), also indigenous in America but now widely spread in all countries round the Mediterranean Sea. What in this latter plant most people consider as the leaves is in truth the peculiarly broadened stem, while the true leaves at first have the shape of small green cones and later change into the well-known spines. If we cut through such a succulent leaf or stem we will be struck by the amount of fluid contained in it; it is stored in the cells of an abundantly developed ground-tissue, and its presence, while it causes the thickness of the respective parts, enables the plants to live and thrive in localities where all ordinary plants would die from want of a regular supply of moisture.

Sugar-solutions, as you know, are a frequent occurrence in the "flesh" of **fruits**, which is almost entirely made up of ground-tissue. Under natural conditions, this flesh, if it does not serve as food for animals and thus aid another important purpose of the plants (p. 378), must decompose before the seeds contained in the fruits commence to sprout; it is imaginable therefore that its original significance was to enrich the soil round the seeds with material, in some way or other useful to the young plant during its first development. I say "has been", because many of these fruits have subsequently been seized upon as food by Man who has more or less changed them in the course of time by cultivation. The sugar-cane is a plant which exemplifies the occurrence of sugar-solution in the ground-tissue of the **stem**; the remarkable thickness of the latter is in accordance with the large amount of ground-tissue present. In a number of plants, the **root** is used for storing substances among which sugar-solutions and starch again rank first. These roots then assume an unusually bulky shape due to an excessive development of the ground-tissue. I here remind you of the beets (بَنْجَر) and turnips (لِفْت); the root of the sugar-beet (*Beta vulgaris*) in especial is so rich in sugar that in northern countries it is largely cultivated for the manufacture of sugar (beet-sugar).

The last-mentioned plants (and others) are, under normal conditions, so-called "biennial"* plants. They in the first year of their existence only form a number of leaves; the products assimilated by these are stored in the root and the next year serve for the production of a thick stem with flowers and seeds. I just emphasised the word "normal"; indeed it not infrequently happens that under particularly favourable conditions of temperature and nutrition the life-history of certain individual specimens of the respective plants is abbreviated by their developing the stem with the flowers and fruits even at the end of the first year. The phenomenon is, in Europe, well-known to gardeners and farmers by the name of "bolting"; it appears that owing to the length of the warm season and the fertility of the soil in Egypt, it occurs far more frequently, and may even become the rule, in this country.

While in beets and related plants the whole main portion of the root is transformed into a "store-room" others only form local swellings near the ends of certain root-like structures (for further details see p. 381) and stock these with reserve-substances among which, in this case, **starch** holds the first place. These swellings may develop into more or less individualised tubers and serve the plant for the propagation of its race ; for they remain alive after the death of the producing organism, inclusive of roots and root-like structures, and the next year give rise to one or several new plants which form their first parts at the expense of the starch accumulated in the tubers. Practically the most important instance of the formation of such underground tubers is given by the potatoe (*Solanum tuberosum*, بطاطس) ; another, well-known in this country, is the Batata (*Ipomoea edulis*), the tubers of which, in addition to starch, contain a fair amount of sugar, whence its other name "sweet potato" (بطاطه).

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* From the Latin "bis"—twice, and "annus"—year; therefore plants which live two years, in contradistinction to the "annual" plants which live one year, and the "perennial" which live many years.

The bodies by which the higher plants regularly reproduce themselves are the **seeds.** It is a familiar fact that these are very rich in starch, but in addition often contain oils, fats, and other products. You probably know that most of the "vegetable oils" are obtained by compression of the respective seeds, as e.g. the cotton-oil is derived from the seeds of *Gossypium herbaceum* (the cotton-plant), the castor oil from the seeds of *Ricinus communis* (Arabic خروع), etc. Starch as well as these oils are contained in the ground-tissue of the cotyledons and represent a first food-material for the plants developing from them (see p. 333). These examples may suffice to show you how the ground-tissue is utilised for the purpose of storing. Let me repeat that the cells of this variety have thin walls and a fairly regular polyhedric shape.

I cannot in this connection entirely omit mentioning that a large number of plants within their ground-tissue (not,however, exclusively in this) contain more or less long tubes, either simple or ramified, which enclose fluids of (usually) milky appearance : the so-called "**Milk**"-, or "**Latex**"-**Tubes** *. You certainly have noticed that when you break the leaf of a fig-tree, or a poppy-plant (أبو النوم), or a Batata-tuber, a drop of a white fluid oozes out from the broken surface; this is the content of the latex-tubes. We do not yet exactly know what part these fluids play in the life of the plants; the fact is that they are the chief suppliers of the technically important gums, resins, etc., mentioned on page 334 and various other vegetable products used as drugs in medicine (the sap of the poppy-plant, for instance, supplies the opium). Histologically, the latex-tubes seem to be derived from the ground-tissue and, when fully developed, are considerably elongated cells which either remain single or fuse at their ends, thereby forming a continuous system of canals, which extends through almost the whole body of the plant.

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* "Latex"—Latin designation for fluids of all sorts.

The second principal function allotted to the ground-tissue is strengthening the body and giving it resistance to traction and pressure. Looking at a tree, you may easily understand that the stem (and other parts commensurately) must, on the one hand, be stout enough not to be crushed by the weight of all the branches, leaves, and fruits it has to carry, and must, on the other, be both coherent and elastic enough to partly resist and partly yield to the side-pressure exercised by winds. This resistance is given to the body of the plant by a variety of the ground-tissue which we distinguish as "**Mechanical**" or "**Supporting Tissue**". Its elements display the attributes of their particular function even in their outward appearance; for they are no longer thin-walled and polyhedric but, apart from minor variations (which exist), have an elongated fibrous shape and usually such considerably thickened walls that their internal cavity becomes reduced to a thin canal (e.g. Fig. 4, Pl. XVII). Their ends are always tapering, and by pushing in between those of the adjoining cells increase the firmness of their mutual connection. Among themselves, they are generally classified into four chief varieties; the "collenchymatous" cells, the "sclerenchymatous" or "bast-cells", the "libriform" or "wood-cells", and the "sclereïds" or "stone-cells.

The **collenchymatous** * **cells** still resemble the ordinary parenchyma-cells in so far as they possess thin walls; they are, however, prismatical in shape and their mechanical function is indicated by a considerable (inward) thickening of their angles. The collenchymatous tissue in transverse section thus exhibits the characteristic picture given in Figure 1, Plate XVIII. The peculiar conformation of the cell-walls warrants a comparatively large elasticity, and the tissue is accordingly prevalent in the petioles.

The **sclerenchymatous** † and **libriform** ‡ **cells** have the shape of long, thin fibres with uniformly thickened walls perforated only by scarce, cleft-like pits of insignificant size (Figs. 4, 5, Pl. XVII; Fig. 2, Pl. XVIII). The two varieties differ from one another mainly by their position within the plant, of which we shall have to speak later (see p. 359). In certain plants the sclerenchymatous fibres are remarkable for their length which may reach forty and even seventy millimetres. Such long fibres are very useful for practical purposes; as a matter of fact, what we popularly call "hemp" and "flax" are scientifically the bast- (and wood-) fibres of the plants bearing the same names (*Cannabis sativa*, Arabic قنّب, and *Linum usitatissimum*, Arabic كتّان). You know from experience that "linen" (made of flax-fibres) is much more durable than a similar tissue made of cotton-fibres; the reason is that the flax-fibres are mechanical elements of the plant, the cotton-fibres are not. Both can by their histological characters be distinguished from one another under the microscope as easily as they can from silk-threads (pp. 188, 337).

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* From κολλάω—to glue together, fasten; ἔγχυμα—see note *, p. 340.

† From σκλερός—hard.

‡ From the Latin "liber"—the bast under the bark of trees.

The **stone-cells**, finally, have a polyhedric shape and very thick, distinctly stratified walls perforated by numerous, fine, and sometimes ramified pits (Fig. 3, Pl. XVII). Wherever they join in large numbers they form a tissue of almost stony hardness, as exemplified by the "stones" of certain fruits, e.g. dates (نواة البلح), the "shells" of nuts (قشر البندق), etc.

A third variety of the ground-tissue, peculiar to plants, has its prominent character in the presence, within the cells, of chlorophyll-grains. Although these are also found in various other cells of the vegetable body, they are specially accumulated in the parenchyma-cells of the leaves; giving these an appearance of their own. As these chlorophyll-cells are the chief assimilating elements of the plant, the tissue they compose is conveniently differentiated as "**Assimilation-Tissue**" (*Pa* and *Sp* in Fig. 3, Pl. XVIII; the small dark dots representing the chromatophores).

The **meristem-tissue*** is a very interesting and important constituent of the body of many higher plants. I have said above that it has no counterpart in the full-grown animals. You will remember that the animal body as a rule ceases to grow when it has reached a certain size, but may, notwithstanding, still live for a long time. The growth is discontinued because the body-cells have, at that stage, in the main assumed their definitive shape and function and in this condition do no longer multiply by division. The power of dividing, as a matter of fact, is a peculiarity of embryonic, or, at least, young cells (see p. 336).

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* Μεριστός (from μέρος see note *, p. 133)—something divided, or capable of being divided.

If we now compare the plants from the same point of view we find conditions similar to those just described only in the so-called annual plants (note *, p. 343). Taking as an example an individual of barley (شعير), or one of flax (كتان), we see that these plants develop from their seeds and grow by a multiplication of their cells ; when all parts are unfolded, and flowers and seeds formed, the main bulk of the body-cells have assumed their definitive shape and function ; the plants still live for a time and then die. If, on the other hand, we look at a tree (e.g. a Lebbakh-tree, *Acacia lebbakh*) we see that the individual developing from the seed does not die after the first year of its existence ; it only goes through a period of latent life (p. 11) and then resumes its growth by forming, at the ends of those already in existence, new roots and new shoots, these latter with leaves and (later) flowers and seeds; that it goes again through a period of rest, and so on for many years. To this form of growth, which is characteristic of the perennial plants (note *, p. 343), we have a counterpart neither in the animals nor in the annual plants; we distinguish it as "**Secondary Growth**" from the "**Primary Growth**" of the annual plants **and** the perennial in the **first year** of their existence.

Knowing now that any growth by multiplication of cells can only be brought about—in the vegetable body even more markedly than in the animal—by young, as yet undifferentiated cells, we must expect to find such cells in all those parts of a plant which are capable of secondary growth, while no similar cells are required in parts that have no secondary growth. We indeed find cells as described in the roots, the stems and the boughs of trees (and perennial plants in general), and call the tissue they compose "meristem-tissue"; there is no meristem-tissue in the annual plants, nor is there in the leaves, the flowers and the fruits even of trees, because these parts, in contra-distinction to root and shoot, have a limited size, and therefore no secondary growth.

In accordance with the embryonic character of the meristem-tissue its cells, as just stated, are not yet differentiated and display the original appearance of the vegetable cell, i.e. a thin cellulose-wall, a protoplasm without vacuoles, and a distinct nucleus situated in, or near, the centre (Fig. 5, Pl. XIX). The nuclei divide by mitosis and the products of the consecutive cell-divisions arrange themselves in a very regular manner distinctive of the meristem-tissue. A convenient object for studying its microscopic appearance and the way in which it produces new parts of the body is the tip of a growing root.

In a longitudinal section of this, passing through the axis (Fig. 4, Pl. XIX), we see a large number of rectangular cells distinctly arranged in layers (in the drawing rows) which manifestly start from an area somewhat behind the apex of the section (*CG*, in Fig. 4). This area is the actual **centre of growth**, or the "**Growing Point**", i.e. the place where cell-division is going on most intensely. Now, it is not difficult to understand that the new cells arising by any division, by coming in between the central and the more peripherally situated cells already in existence, must push the latter away from the centre, to be pushed away in their turn by the cells originating through the next division. Under these circumstances, the cells which, in a section, are found nearest to the centre must always be the youngest, while the others become older in the measure as they lie farther away from the centre. If you fully understand this constant production and gradual shifting of the cells you will also understand why the centre of growth, in the tip of a growing root, while it is in activity, constantly pushes itself forward and away from the base of the root; in a similar way, perhaps, as a mason who builds up a wall, or a chimney, by placing ever fresh bricks under his feet, would lift himself ever higher into the air, and away from the ground. Since, further, the relative age of any cell is indicated by its distance from the growing point we in the section find **side by side** all the changes which the cells **subsequently** undergo in the course of their development. One single favourable microscopical section may thus be an excellent object for studying the transformation of the vegetable cell from its embryonic into its definitive state (Fig. 4 is only a short terminal portion of such a section).

While the new cells produced by the centre of growth, in the lateral and backward directions form new portions of the root, those produced anteriorly enter into the formation of a special structure called the "**Root-Cap**" (*RC*, Fig. 4, Pl. XIX). It actually covers the tip of the root after the fashion of a cap and protects it from injuries. In accordance with the principle of growth just explained it also grows continually, but does not increase in size (as the root proper does), because its peripheral layers constantly wear away in the measure as new cells are produced from the centre (cells in the act of scaling off are visible on either side of the root-cap in Fig. 4).

What has here been exemplified by the growth of the root is true for the growing tips of the shoot, except that these parts form no caps. They grow by the activity of a meristem which forms a centre of growth near the apex, and thence constantly supplies new cells without being itself used up in the process.

Conditions are somewhat, though not essentially different in the stem, which has to increase in width, that is, in a transverse direction instead of longitudinally. Theoretically considered, two possibilities would lead to this end : the addition of new substance might take place in the axis, i.e. from inside outward, or it might take place on the surface, i.e. by apposition of new substance to that already existing. On looking a little closer we will see that both alternatives meet with certain difficulties; especially the former. For any new body-substance arising in the axis of a stem would necessarily press upon all the older, i.e. more peripherally situated layers, and compel these to give way. This might be done by simple enlargement under continuous multiplication of the constituent cells; in this case, however, the latter would be prevented from assuming their definitive shape and function. If, on the other hand, they do assume these, the cells will lose the capability of dividing, and a pressure from inside would eventually lead to a bursting of the outer layers, in which case the continuity of the whole body and the regular nutrition of its parts would suffer. A growth of the stem from inside outward would thus invariably lead to consequences incompatible with other vital requirements of the plant.

There remains, then, the second alternative, viz. that of an apposition of new substance to the surface of the stem. It is clear that this would not disturb the conditions in the older, inner parts, the cells of which might undergo their changes and assume their functions; but it would interfere with the function of the epidermis. As this represents the outermost layer of the body the production of new substance by cell-division would be incumbent upon it. Then, however, its cells would have to remain embryonic, i.e. capable of dividing, and it would be impossible for them to transform, as they actually do, into particular protective organs, while they themselves, delicate and soft as they are, would remain unprotected. So we see that neither of the two alternatives which at first seemed possible perfectly comply with the exigencies of the vegetable organism, one entailing difficulties even more numerous and more serious than the other.

It is therefore not surprising to see that the real method of growth adopted by the stem is a compromise between the two existing possibilities, but, on the whole comes very near to that described above in the second place. In other words, the growth of all those parts of the plant which secondarily **increase in thickness** starts from a centre which lies somewhat below the epidermis and has the shape of a layer of meristemic cells all round the surface. At the growing tips of shoot and root this layer imperceptibly passes into the general meristem there situated; in fact, the new cells produced at each centre of growth do not subsequently all transform into their particular shapes, but some remain embryonic all the time and thus represent the layer above-mentioned. Though meristemic in nature and origin it has a different purpose inasmuch as it has to provide, not for the first formation of new parts of the body during its secondary growth, but merely for the increase in thickness of already existing parts. In accordance with this special function it is differentiated from the meristem proper under the name "**Cambium**" *.

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* Probably from the Low Latin "cambire"—to change.

The cambium accomplishes its work in such a way that at intervals it produces new cells towards both its inner and outer surfaces. The cells in the former position, while assuming their definitive shape, are added to the bulk of the stem which thereby increases in diameter by apposition. Since, further, all these new cells are produced almost simultaneously they in their entirety assume the shape of a continuous sheath encircling the previously existing layers. The process is repeated, usually once, every year, and hence the fact that when we cut the stem or twig of a tree perpendicularly to its axis it displays the picture of a system of fairly regular concentric lines, the so-called "**Annual Rings**". The interval between every two of these rings represents the thickness of the mass which has been added within the year, and the whole number of the rings thus fairly accurately indicates the age of the stem.

The first consequence of this constant increase in diameter is a stretching of the cambium itself which, however, can give way without difficulty by a multiplication of its cells. The pressure is passed on to the layers outside, and is there intensified by the new cells which are produced by the cambium on its outer surface. The whole outer-cambial portion of the stem practically grows from inside outward, and its layers are consequently continually distended; the epidermis, naturally, most of all. We here have the reason for the fact already mentioned (p. 337) that in stems which increase secondarily in width the epidermis is sooner or later destroyed; its place, as we said, is taken by products of the "underlying tissue" which is, ultimately, the cambium. The new layers this produces, as they are constantly being added on the inside of the older, ought to finally transform these into a thick coat. They actually do so in certain trees and we then clearly see the results of the passive stretching connected with the growth from inside outward in the shape of numerous more or less deep breaks renting the surface of the coat in a chiefly longitudinal direction. I think the phenomenon will be familiar to you from what we call the "bark" of the trees. In other trees the surface retains a fairly smooth appearance, but nevertheless presents small clefts on close inspection. In these cases the superficial layers of the bark scale off continually and in small portions before they reach any considerable thickness.

The cambium, owing to its having the shape of a thin layer of cells and its being located somewhat below the surface, divides the whole stem of a tree into two zones, viz. a thick axial mass and a comparatively thin, enveloping coat. These parts are scientifically distinguished, the former as the "**Xylem**" * or "wood"-portion, the latter as the "**Phloem**" † or "bast"-portion. Both show certain structural characteristics of which we shall have to speak later. Being only connected by the thin cambium which, moreover, consists of soft, thin-walled cells, the two portions are usually easily separable; various plants (as e.g. willows, Arabic صفصاف) even enjoy a certain reputation for the easiness with which their cortex comes off.

The presence of the cambium is the internal cause of an interesting and practically important phenomenon observable, though to a varying degree, in many plants. You may frequently notice in this country that, when a new Lebbakh-tree is to be planted, they simply take a fresh stem, or branch, cut off squarely above and below, and place it upright into the earth. While some of these bare stems die subsequently, the great majority develop into new trees by forming branches and leaves at their tops and roots at their bases. They are enabled to do so by the presence of the cambium. While under ordinary circumstances this only has to provide new wood-cells on its inside and new bast-cells on its outside, the fact that certain important parts of the body are missing induces it, so to speak, to interrupt its normal activity and produce instead those missing parts. Being meristemic in origin, it reassumes its original nature; forming, chiefly near the cut surfaces but also in other places, new centres of growth the cells of which, just as ordinary meristem-cells, are capable of supplying all the histological elements of the vegetable body, and thence onwards maintain themselves as meristem-cells in the growing points of the newly formed shoots and roots. The constructive material for the first new parts is taken from the reserve-substances deposited in the cells of the stem. The capability of in this way reproducing lost parts is extraordinarily developed in certain plants, but is reduced or even entirely absent in others (compare here pp. 421 ff).

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* From the Greek ξύλον—wood.

† From the Greek φλόος—the cortex and bast of trees.

3.—Organs.

When speaking of the tissues of the animals we saw (p. 40) that they combine to form the organs of the body; but do so in such a way that each organ receives those tissues only, the special function of which it requires for its work. Conditions are quite similar in the plants. The chief organs of the ordinary plant are (1) the roots; (2) the stem (or stalk); (3) the leaves; (4) the flowers. We will now shortly discuss the general structure of these organs in connection with their particular functions.

The **root**, as we already saw, has to absorb the water and salt-solutions required by the plant for its growth. As they are contained in the soil the root has to spread in this. While doing so it assumes the further function of fixing the whole body firmly in the ground. The entire function of the root (or roots) is therefore in part nutritive, in part mechanical; a fact which in all larger roots finds its expression in a distinct division of labour.

Absorption of fluids by osmosis, generally speaking, can be satisfactorily accomplished only by thin-walled cells, and can, in particular, only go on through an epidermis not (or not yet) metamorphosed into a protective organ (p. 336). We find an epidermis of this description in the neighbourhood of the growing tips of the root; these are in fact the chief absorbing organs, and in compliance with their task, in the shape of the so-called "**Root-Hairs**", develop additional structures for enlarging their surface and intensifying their contact with the soil. The root-hairs are comparatively long, thin, cylindrical outgrowths of the epidermal cells (quite similar to that marked *H* in Fig. 3, Pl. XVIII), and, growing all round the surface, in their entirety represent a structure similar to the brushes we use for cleaning the chimneys of lamps. They are gradually formed by the epidermis-cells and thus are still absent in the youngest portions of the root which immediately follow the root-cap (they are therefore not visible in Fig. 4, Pl. XIX), while again disappearing, owing to obliteration, farther backwards, i.e. in the older parts of the root.

Their adherence to the particles of the soil is very intense and their absorbing power is even, comparatively speaking, enormous. For, it may here be stated that, owing to the absence in the plants of any organ corresponding to the heart of the animals, the circulation of their saps, and quite especially the ascension of the fluids from the roots to the top-parts of the shoot, must be effectuated by another force. This is given in the "**Root-Pressure**", i.e. the power with which the root-hairs absorb water and salt-solutions. It is naturally only a property of the living roots and consists in the protoplasm of every cell absorbing fluid to such an extent that the latter becomes compressed within the cell and gives it a certain hardness, in a similar manner as the soft indiarubber-tyre of a bicycle becomes hard if air is pressed into it. We technically call the pressure under which the fluid stands in the living vegetable cells the "**Turgor**" or the "**Turgidity**"* of the cells; it is completely absent in dead cells because the active agent producing it is the living protoplasm inside the cell-wall (compare here the withholding action of living protoplasm in the case of other substances; pp. 245 and 300).

The fluids accumulated in the cells with such force are passed from cell to cell, until eventually they are handed over to the vessels which convey them to their destination. It has been found by experiment that the roots of certain plants may in this way lift water up to a height of eighteen metres. Many plants, however, even grow beyond this limit and accordingly lift water up to much greater heights. The root-pressure is in these cases supported from the opposite side by a sucking action resulting from a normal evaporation of water from the leaves. The plants, as the technical term is, "transpire" and the amount of fluid lost by this **Transpiration** must be continually replaced from the roots. If for some reason or other this cannot be done the plants "wither".

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* From the Latin "turgere" — to swell, to be puffed up.

The phenomenon will be familiar to you and shows, by the way, that the erect attitude of especially the youngest, newly formed parts of a plant is to a large extent due to the turgor above mentioned. From the example of the bicycle-tyre you will understand that the more the pressure decreases in connection with a reduction of the fluid, the more the cells, and finally the whole parts they compose, must become flaccid. This phenomenon is of course not observable in parts. the mechanical elements of which have fully taken up their function ; as most of these elements even die with the assumption of their definitive shape changes in the turgor have no influence upon them, and the respective parts retain their form whether fresh or dry. You may easily observe this in a newly cut twig of a tree, if this is allowed to dry. Although all its cellular constituents lose their natural turgor by evaporation, only the (soft) apical portion assumes a drooping position because it is kept erect solely by the turgor of its as yet soft-walled cells. We thus see that the absorbing activity of the root-tips, apart from its being a chief factor in nutrition, has still another important significance in the life of the plant.

What has just been said naturally implies that the fluids absorbed by the root-tips are conveyed to all the rest of the plant's body. This actually is the task of the remaining portions of the root ; while accomplishing this work they have, moreover, to prevent an unnecessary evaporation of the fluids (which might, for instance, easily take place in dry superficial layers of the soil), and they have to fix the whole plant in the ground. We accordingly find in them vascular bundles and an abundant ground-tissue developed in part into mechanical, in part into protective elements. It is clear that the latter, owing to their special duty must occupy the periphery; as a matter of fact, the older parts of the root soon lose their epidermis, and in its place receive a thick coat of cells, the walls of which cutinise, or suberise, and thereby form a protecting envelope, the "**Cortex**". The central portion of the root, which in its entirety is differentiated from the cortex under the name "**Central Cylinder**", is made up of the mechanical elements, chiefly wood-fibres which compose a thicker or thinner axial strand, and vessels which are arranged round this in a regular order. This general arrangement is shown in cross-section (through a somewhat young root) in Figure 3a, Plate XIX. In order to understand finer structural details we must premise some words about the composition of the

Vascular bundles. The vessels, as already emphasised (p. 338), always occur in bundles, each of which contains both tracheae and sieve-tubes arranged in such a way that the former constitute a strand of their own which faces the axis of the respective organ, while the latter form another strand which faces the surface. Both strands are supported by mechanical elements which between and round the tracheae are libriform cells, whereas the sieve-tubes are not exactly surrounded, but merely accompanied on their peripheral aspect by a strand of sclerenchymatous cells. This is the difference in the position of the two varieties of elements to which reference was made on page 346. A cross-section through a vascular bundle thus gives an average picture like that drawn in Figure 2, Plate XIX. You here see, above, a fairly thick pack of sclerenchymatous cells marked *Scl*, and closely applied to their lower boundary a layer of sieve-tubes *ST* (in some of which the sieve-plates are visible). This is the phloem or bast-portion which makes up the peripheral half of the entire vascular bundle. Below it, there is the axially situated xylem or wood-portion, showing the cross-sections of a number of fairly wide tracheae *T* surrounded by numerous narrower libriform cells *Scl.* Wood-portion and bast-portion are in the figure separated by a layer of very thin-walled cells marked *Ca*; this is the cambium in cross-section. From what we said above (p. 353) about its function you will understand that by division of its cells it can add on its outer side (above in the figure) new sieve-tubes, and on its inner side (below in the figure) new tracheae, to those already in existence. Vascular bundles in which such a layer of cambium is present and which on this account are able to grow, are called "open" bundles; in certain plants the bundles are "closed", that is, they contain no cambium and are accordingly unable to increase in capacity.

Let us now return to the minute structure of the root. We said that its vascular bundles and mechanical elements are collected in the central cylinder. The respective conditions are illustrated in Figure 3b, Plate XIX, which represents a small portion of the cross-section 3a more highly enlarged. Cortex (composed of the epidermis *Ep* and a thick layer of ground tissue *Gr*) and central cylinder are marked *Co* and *CC* respectively. In the latter you perceive four strands of tracheae *T* supported by libriform cells and three strands of sclerenchymatous cells *Scl* (the sieve-tubes applied to their axial surfaces are too small to appear distinctly). Between them there is a thin layer of cambium *Ca*. A particular feature in the arrangement of the parts which compose the central cylinder of the root is that the phloem-portions of the vascular bundles regularly coincide with the intervals between the xylem-portions (as also indicated in Fig. 3a). The manner in which a root built up as here described is able to grow in thickness need I think not be explained further.

The **stem** in its structure in the main resembles the root, as in fact its function (namely, the supporting of the other parts and the protecting of the vessels leading to and from these), also corresponds to that of the older portions of the root. There are, however, differences which owe their origin to particulars in the function of the stem (or stalk). Reflection will show, first, that the supporting role this has to play differs somewhat from that of the root. The latter moores the plant, as it were, in the ground and thus has to resist almost exclusively to traction; the stem, on the contrary, carries all the over-ground parts of the plant and thus has to meet pressure, both from above (as exercised by the weight of the parts) and from the sides (as exercised by winds). This difference leads to an interesting change in the general structure of shoot and root. Examination of a transverse section of any stem reveals at a glance that it has its supporting tissue not in the axis as a kind of chord, but near its surface in the shape of a hollow tube. This change is in evident accord with certain laws of Physics. A cylindrical piece of some material is most resistant to traction if it is solid, and we therefore make cords and ropes solid; but it gains in resistance to pressure, from above and the sides, if it is hollow. We therefore use hollow pillars and hollow supports in our modern constructive technique, just as we see that the supporting organs of the animals, namely, the bones, consist of a hard outer wall and a cavity inside which may, or may not, be filled with a soft mass serving other purposes. The stalks of the plants follow the example, as they practically have to perform the same function; on examination, they prove to be either completely hollow and merely filled with air (as e.g. in many grasses), or they contain in their centre a soft parenchyma called "pith" which is sometimes used for storage-purposes.

The mantle of resistant substance which gives the stalk of the plant its stability is in the main represented by the **vascular bundles** which are usually present in large numbers. Individually, they have the structure above described and illustrated in Figure 2, Plate XIX; that is, their bast-portions, facing outwards, are situated exactly opposite the wood-portions which face the axis of the stalk. It is brought about in this way that the entire bundles represent more or less solid strands, easily distinguishable to the naked eye, and occasionally coming out of the surrounding tissues as such when the stalk of a plant is broken off. A cross-section through the somewhat young stalk of a perennial plant, if seen under a low power, thus gives the picture shown in Figure 1a, Plate XIX. The vascular bundles *VB*, each composed of a (darker shaded) bast-portion *p* and a (lighter shaded) wood-portion *x*, are arranged in a fairly regular row all round, and slightly below, the surface. The cambium, appearing as a light band marked *Ca*, not only separates the bast- and wood-portions of each vascular bundle but even crosses the intervals between every two neighbouring bundles, thus forming that continuous sheath previously described as separating the whole stalk into the voluminous axial xylem and the thinner enveloping phloem. A part of this section is depicted under a higher magnification in Figure 1b, which I trust will require no special description.

Modifications in this general arrangement of the constituent parts of the stalk, or stem, are numerous among the multitude of existing plants, but cannot here be taken into account. Mention may only be made once more of the fact already explained on page 348f that in the annual plants the stalks are unprovided with cambium and accordingly cease to increase in diameter when all the histological elements have reached their definitive size. In the stems of shrubs and trees, on the other hand, the cambium, by its periodical activity, gradually produces the substance known as "wood". That in the scientific sense this is an aggregation of tracheæ and libriform cells need not again be explained; in reality, its structure is somewhat more complex than has here been described, but these are details of special botanical interest. The new material produced by the cambium on its outside develops into bast-elements, i.e. sieve-tubes and sclerenchymatous cells, but does not usually give rise to a considerable thickening of the cortex because, firstly, it is as a rule less abundant than the mass of wood-elements generated within the same time; secondly, it is continually distended by the increasing diameter of the stem, and thirdly, it is constantly dying and scaling off at the surface.

A minor difference concerning the behaviour of the vascular bundles in root and stem has its reason in the fact that the stem, or stalk, carries leaves, which the root never does. The consequence is that the vessels of the root remain unbranched and only join to form larger bundles as they run from the root-tips to the base of the stem, while the vessels of the latter not only send branches into every leaf, but also intercommunicate among themselves, in order to secure an equal distribution of the food-materials to all parts of the body. The communications mentioned are chiefly found at the levels where the leaves branch off from the stalk, but otherwise show variations in detail. I limit myself here to the statement of their existence.

The **leaves** have the function of assimilating, with the help of sunlight and chlorophyll, the carbonic acid of the air under concomitant consumption of water. Their structure displays a manifest adaptation to this task. Considering, first, their outward appearance we see that they are thin blades with large surfaces as are needed for an extensive contact with both the air and the light. For the latter purpose in particular they are disposed on the plant not exactly one above the other, but more or less sidewards, so as to prevent the upper from throwing their shade on the lower. All leaves as much as possible accumulate near the top of the plant while turning their surfaces to the source of light, but gradually die at the base owing to their becoming older and more shaded at this place. Most leaves to the naked eye present the well-known markings known as the "**Nerves**" or "**Veins**". These show a varying, but always regular arrangement, commencing thin near the edges, growing thicker towards the middle, forming, by transmitting numerous irregular and often branched bridges to neighbouring vessels, so-called anastomoses (see note ‡, p. 243), and finally uniting all into one strand which enters the leaf-stalk (or petiole). The nerves usually do not project on the upper surface of the leaf, but appear as more or less raised ridges on the lower. It is not difficult to infer from this general distribution and appearance that the nerves are supporting organs, destined to stiffen the thin lamina of the leaf.

Passing to the microscopical structure (see Fig. 3, Pl. XVIII), the particular function of the leaves suggests that they should chiefly consist of assimilation-tissue, but naturally contain, in addition, also protecting, supporting and conducting elements. The protecting elements are represented by the Epidermis (*Ep*, Fig. 3) which envelopes the whole leaf in the shape of a single layer of transparent cells with cutinised walls ; their outer surface is often additionally covered by a continuous cuticle (*Cu*, Fig. 5).

Their shape has already been described (p. 336). A number of them may grow out into more or less long hairs (as shown in *H*, Fig. 3), while multicellular hairs (p. 337) are of less frequent occurrence. On the lower surface of the leaf (more rarely on the upper) the epidermal cells are interrupted by the **stomata** already mentioned on page 338. These when seen from above are minute slit-like openings bordered on either side by a bean- or crescent-shaped cell with chlorophyll-grains, and both called the "**Guard-Cells**" of the stoma (*GC*, Fig. 4). In cross-sections (*Sto*, Fig. 3; more highly magnified in Fig. 5) it is seen that the slit between them gives entrance into a system of intercellular spaces to which we shall return presently. The opening and closing of the stomata is brought about by changes in the shape of the guard-cells which, by flattening, reduce the width of the slit between them, by contracting again widen it.

Subjacent to the epidermis we find the **assimilation-tissue** consisting of irregularly prismatical cells densely filled with chlorophyll-grains. Immediately under the upper surface of the leaf, they first form a fairly continuous layer, in which the long axes of the cells are placed at right angles to the surface (*Pa*, Fig. 3). Below these "palisade-cells", as they are called from their shape and arrangement, similar cells follow which, however, have their long axes placed in various directions and have, moreover, conspicuously numerous empty spaces left between them (*Sp*, Fig. 3). The parenchyma these latter cells compose is differentiated from the "**Palisade-Parenchyma**" as the "**Spongy Parenchyma**"; it is bounded below by the epidermis of the under-surface of the leaf.

Of particular interest are the intercellular spaces just mentioned. Though specially prevalent in the spongy parenchyma they also push in between the palisade-cells, and here and there even reach the epidermis of the upper surface as seen in the drawing; in other words, they extend through almost the whole mass of the assimilation-tissue, while at the same time communicating with the outer world by the numerous stomata. If we remember that these can be opened and closed according to exigencies we will understand how the plant is able to meet its requirements as described on page 338.

The supporting and conducting elements of the leaf are represented by the "nerves", i.e. **vascular bundles** which, as in stem and root, result from a firm union of vessels proper with libriform and sclerenchymatous cells. They are normally placed in such a way that their wood-portion (with the tracheæ) lies along the upper, the bast-portion (with the sieve-tubes) along the lower surface of the leaf. All vascular bundles commence quite thin, and with only one or two vessels, at the free margin, and appear in this condition in *VB*, Figure 3, Plate XVIII, as that section is taken from very near to the leaf-tip. In the measure as these vessels coalesce towards the insertion of the petiole they become thicker and their vascular nature appears more clearly, while the supporting elements increase commensurately to form the ridges we see projecting from the under surface of the leaf-blade.

CHAPTER XII.

On the Reproduction of the Higher Plants.

It has already been pointed out that the flowers of the higher plants display an astounding variation in their general shape and arrangement, and that important differences also occur between them with regard to the distribution of the sexual organs (p. 319ff). We must here leave all these differences out of consideration, and limit our study of the structure of the flower to one of those simple and regular types as are offered, amongst the Dicotyledons, e.g. by the (wild) rose, or the poppy (أبو النوم). You are familiar with the general appearance of such flowers. If we examine one with the naked eye, we mainly find the following conditions (compare Fig. 7, Pl. XVIII). There is, first, the flower-stalk (*FSt*), more or less sharply individualised, on the top of which the flower proper rests. The latter consists of a varying number of parts which, whatever particular form and colour they may exhibit, are, in the biological sense, always peculiarly transformed leaves differentiated from the usual foliage-leaves as "**Floral Leaves**". They are arranged in circular rows or "whorls" which, originally, are placed one above the other, but owing to a considerable shortening of the axis between them practically appear situated one inside the other.

In an ordinary flower four such whorls are usually present; there are, if we proceed from outside inwards, (1) the "**Sepals**" (*Se*), a circle of green leaves often starting from a common basal swelling, which compose the "**Calyx**" (*Ca*) and completely envelope the flower so long as it is in the state of the "bud".

Inside the calyx and its leaves, we find (2) the flower-leaves proper, or "**Petals**" (*Pe*), which in their entirety compose the "**Corolla**". The petals may be present in one or several circles, they may be isolated or united at their bases, they may on the whole present a very varying appearance—their most outstanding character is always a bright colour (white, yellow, red, blue), but hardly ever a green colour. Calyx and corolla together make the "**Perianth**"* and are, as we might term it, auxiliary, or secondary, sexual organs inasmuch as they have an important part to play in the sexual process, but are not sexual organs properly speaking. These latter are represented by hair- or stalk-like formations inside the corolla and consist of (3) the male organs or "**Stamens**" (*Sta*), filiform structures often present in large numbers and bearing at their free ends each an appendix varying in shape and colour, the "**Anthers**" (*An*). These latter are the "testes" of the plant and produce what to the naked eye appears as the well-known "dust of flowers" and is scientifically termed the "**Pollen**". If examined under the microscope it proves to consist of countless minute grains which have an irregularly marked surface, but otherwise characteristically differ in appearance with the different species; they contain cells corresponding to the spermatozoa of the animals. The stamens surround the fourth and last whorl of floral leaves which are termed "**Carpels**" and consist each of an upper filiform portion, the "**Style**", and a basal swelling. Usually, all carpels coalesce altogether into a single organ, the "**Pistil**", which then occupies the axis of the flower (*Sty*); frequently, their apical portions remain free and the pistil appears branched at its upper end; more rarely, the carpels do not unite at all, there being thus several pistils. Each carpel has the tip of its style transformed in some way so as to make it appear as a special structure. This is the "**Stigma**" (*Sti*); its surface is as a rule uneven, moist, or sticky. The basal swellings (see above) are always present, but vary much in details; when reaching down into the calyx they cause the swelling of this latter (*Ca*, Fig. 7, Pl. XVIII), while in a large number of other flowers they are placed above the calyx and, in this position, easily visible. They enclose the eggs or "ovules" (*E*) of the plant (p. 322) and therefore are equivalent to the **ovaries** of the animals.

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* From ἄνθος—flower; for περὶ compare note*, p. 84.

This is in principle the structure of an average dicotyledonous flower. For the purpose of propagating the race the pollen-grains produced in the anthers must be transferred on to the stigmata of the carpels, the uneven or moist surfaces of which are exactly fashioned to retain the pollen even after quite a superficial contact. When a pollen-grain has thus been caught, its cellular content breaks forth from the protecting envelope and, entering the tissue of the carpel, makes its way down within this until it reaches one of the egg-cells concealed in the basal swelling, with which it fuses. The minute phenomena connected with this fertilisation are essentially the same as those with which we are acquainted amongst the animals. However, interesting though they may be, they cannot here be described; nor can the processes which accompany the development of the fertilised eggs into seeds. What we are able to observe without the help of magnifying glasses is that the flowers, after having bloomed for a day or two, wither and drop, while the fruits gradually appear in their place. Anatomically speaking, the latter are nothing but the basal portions of the carpels which enlarge considerably as the egg-cells they enclose transform into the seeds. You may easily convince yourselves of these relations between flowers and fruits by observation, for many flowers when attentively examined already reveal in their centre a fruit of minute dimensions, while many fruits, even when quite mature, still bear at their apices the withered and dried remnants of the original style (or styles).

One of the most interesting chapters in the general biology of the plants concerns the **external conditions** under which the **fertilisation** of their egg-cells takes place. On account of the fact that by far the greater majority of the dicotyledonous flowers are hermaphroditic the union of egg and pollen would appear to be the easiest thing imaginable ; and yet it is not. When speaking of the corresponding conditions in the animal kingdom we saw that the natural way to ensure the production of a healthy and vigourous progeny is by the union of sexual cells derived from **different** individuals (p. 153f). This way must be taken in all unisexual animals, but is also the rule for the hermaphrodites, for these reproduce themselves by cross-fertilisation despite the existence of male and female organs in their bodies, and resort to self-fertilisation only in cases of need, i.e. if companions are scarce or altogether absent. It is interesting though not surprising to see that an exactly similar law governs the sexual life of the plants ; in other words, that, in these also, **foreign fertilisation** not only yields a numerous and strong progeny, but self-fertilisation, if not at first, yet after consecutive repetitions, fails to do so and is, when and where it occurs, a supplementary mode of propagation.

The special structures and contrivances which flowers may develop for the obvious purpose of facilitating foreign fertilisation at the more or less absolute exclusion of self-fertilisation are manifold and sometimes wonderfully ingenious; unfortunately, they are of too special a nature to be dealt with in these general lectures. As an easily comprehensible instance out of many I will here only mention that in various flowers the stamens are distinctly longer, or distinctly shorter, than the pistil; their mere length thus making it impossible for the anthers to come into contact with the stigmata and depose their pollen on these. If in some such flowers the pollen is artificially transferred onto the stigma, it is found to remain inactive, and in a few special plants it even acts as a kind of poison, damaging and eventually killing the whole plant. In other plants a fertilisation of the egg-cells by the pollen of the same plant, or even the same flower, does take place, but is, under natural conditions, frequently not resorted to until the possibility of foreign fertilisation has for some reason or another been foregone.

Under such circumstances, foreign fertilisation, or, as the technical term is, **foreign "Pollination"**, obtains the most vital importance; however, as the plants are practically immobile, it is clear that they must utilise outward agencies for accomplishing it. In fact they do so and in each case their genital organs show striking adaptations to the particular nature and the particular mode of action of the agent chosen. We here come to another most interesting chapter in vegetable biology; but as our time is limited, mention can only be made of some of the principal particulars.

Among the factors which in nature effect the transfer of the pollen-grains of one flower to the stigma of another the chief are **wind** and **animals**, especially Insects; we accordingly distinguish "**Anemophilous**" and "**Entomophilous**"* plants. The flowers of both differ so characteristically from one another that in most cases the mode of their pollination can be told from their structure.

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* Greek; from φιλέω—to like, be fond of; ἄνεμος—wind; ἔντομον—incised, Greek equivalent for the Latin term "insectum" (see also note †, p. 233).

In the **anemophilous plants** the pollen is carried to the stigmata by the wind. The actual fertilisation of the egg-cells is here entirely a matter of chance, for it is clear that the plants cannot exert any influence upon the wind. What they can do, however, is to develop peculiarities apt to assist the wind in the work it has to perform in their service. Such peculiarities exist and the chief are these: (1) the pollen-grains are so light that the faintest draught suffices to lift them up and keep them afloat for a long time. They are (2) produced in such enormous quantities that they outnumber the egg-cells hundreds and thousands of times. and on certain occasions practically fill the air for long distances. The stigmata (3) assume an uncommonly large and irregular surface, on which a drifting pollen-grain is much more likely to be caught than it would be on a small and smooth surface. Most anemophilous plants, lastly, display a tendency to grow in large communities side by side, a fact by which an interchange of pollen is greatly facilitated.

In order to see the practical working of these peculiarities you may recall to your minds the date-palms and the various kinds of cereals which are the principal representatives of the anemophilous plants in this country. The date-palms are dioecious and wherever undisturbed grow in groves where the pollen produced by a single male, light and abundant as it is, can easily spread and fertilise many females in the neighbourhood. You certainly know of the habit of the fellahin who at the proper time either shake cut male flowers about the female ones, or even tie a piece of a flowering shoot of a male tree between the flowers of isolated females; the habit is biologically well founded, for it ensures a pollination of these isolated females which otherwise would remain unfertilised owing to the absence of males. The maize-plant (ذره شامى) is monoecious, bearing at the summit of its stalk a panicle of male flowers (called in Arabic شُرَّابَه), while one or several spikes of female (in Arabic كوز) appear between the leaves below. These female flowers are remarkable for a thick tuft of hair-like structures adorning their apices; the tufts are the stigmata transformed in this manner in order to offer as large a surface as possible to any drifting pollen coming their way. If at the right time you give a gentle knock at the stalk you will see clouds of a fine yellowish dust come off the male flowers; this is the pollen liberated, when perfectly mature, from the anthers by the slightest external disturbance and carried about by the wind between the female flowers below. In wheat, barley, and other cereals, conditions are quite similar, with the difference only that the flowers of these grasses are hermaphroditic.

If we review the flowers of these anemophilous plants with regard to their outward appearence we will notice that they are all remarkably inconspicuous owing to the absence of a brightly coloured corolla; they are, further, usually unprovided with any particular smell. The significance of these negative distinctions comes clearly into evidence if we cast a comparative glance at the flowers of the

Entomophilous plants. The agents which effect pollination are here Insects, that is, animals endowed with voluntary movements, and sense-organs to instigate these movements. Unlike the wind, these agents can be influenced by the plants, and the safest means to attract them and secure their services would, theoretically considered, be the offering of food.

The pollen itself and certain sweet fluids secreted from the bottom of flowers and known as nectars are indeed a very favourite food with many Insects. If we admit that the plants prepare this material for the use of Insects, if would only be logical to further assume that they also advertise, so to speak, its existence by means which are perceptible for some distance and thus likely to entice the Insects to visit the tables laid for them. Such advertising agents are **scents** and **colours**; many single observations have indeed shown that they induce, e.g. bees, even when in full flight, to deviate from their original direction towards the places where the colours are, or from whence the scents emanate. This is what the plants offer to the Insects; let us now see what these, in exchange, are expected to do, and actually do, for the plants.

Most Insects have their bodies more or less densely covered with hairs, scales, or similar adornments. If they settle on a flower and force their way into it to get at the pollen or the nectar, some pollen-grains are fairly certain to become entangled between the hairs and are then carried away to some other flower, where new ones join them, while some of the older may, or may not, be wiped off at the sticky surface of the stigma. If we consider that the daily work of many Insects consists almost exclusively in visiting one flower after another, and that, further, every flower will consecutively be visited by dozens of Insects, it appears hardly possible that in the long run its egg-cells should definitely escape fertilisation by the pollen of a foreign flower. The more so, as many flowers possess particular additional mechanisms which provide that the pollen-grains taken away from one flower must touch the stigma of the next. Lack of time unfortunately prevents me, as it did in previous, equally interesting cases, from entering upon further details. The chief fact, however, will I trust be clear to you, namely, that, under the circumstances given, the Insects are indeed most efficient agents of pollination, and that the plants thus exchange a vital advantage for the various sacrifices they make for the benefit of the Insects. The production of sweet nectars and perfumes and the assumption of striking shapes and colours are as little accidental as were the quite different peculiarities of the anemophilous plants; both are acquired in the interest of a successful propagation of the race which depends, first and foremost, on foreign fertilisation.

I have already mentioned that in many plants **self-fertilisation** also occurs; but it is a peculiar and most suggestive fact that provisions for securing it are usually not made until the flowers approach the end of their period of blooming. In order to make this clear I will only cite one example. We have spoken above of flowers in which the stamens are longer than the pistil: the anthers under such circumstances cannot touch the stigma. But before the same flowers commence to wither the stamens curl inwards and may thus effect a self-pollination of those egg-cells which up to that time have not been fertilised with foreign pollen by Insects. Instances like this and many others, different in detail, but all aiming at the same end, tend to show that self-pollination is a sort of safety-measure adopted for the emergency arising from a lack of foreign pollination; for, although this latter is most advantageous, and therefore first sought, self-fertilisation seems to be—in certain cases at least—after all better than no fertilisation.

Besides wind and Insects, agencies like water, small birds, and even snails, may in particular cases serve the purposes of the plants and induce them to develop interesting adaptations; suffice it here to merely mention the fact. If we now remember that all these agencies carry pollen away from the flowers they visit, and transport it to others they visit subsequently, it will be impossible to escape the conviction that under natural conditions it should often happen that pollen-grains get onto the stigmata of flowers belonging to other than their own species. In all these cases the results are identical to what we already know from the animals (compare pp. 168ff). As, in these, the sexual cells of distantly related species do not display any sexual affinity, or, if they unite, furnish an embryo which dies at an early stage of its development, so among the plants the pollen-grains, under corresponding conditions, remain either altogether inactive, or the egg-cells they fertilise perish before they develop into seeds. Just as, however, in certain particular cases, hybrids can be produced (artificially or naturally) by animals of different species, so hybrids are known also in the vegetable kingdom. To all appearance, they arise even more frequently under normal conditions, and can be obtained with greater facility by experiment in the plants than in the animals. We shall return to some such experiments and the general biological results they have led to in a special chapter (see pp. 386ff); for the moment something remains to be said about the reproduction of the higher plants.

It is I think evident that the singular roundabout way these take for ensuring a union of their sexual products has its ultimate reason in their immobility. While the higher animals, freely mobile and provided with sense-organs as they are, can seek and find each other, the plants, being fixed in the ground, cannot do so and therefore must entrust at least one kind of their sexual cells to external agents, in order to have them carried to their place of destination. That this one kind should be the pollen is only natural since we have seen that the male sexual elements are characterised by mobility throughout the world of organisms. Mention may here be made in passing that the difference just pointed out in the method of movement (active, i.e. by their own exertions, in the spermatozoa; passive, i.e. by the intermediation of foreign agents, in the pollen) becomes gradually effaced as we go back to the humbler and simpler organised representatives of both kingdoms, especially those living in fluid media. Recall to your minds what you have learned in the preceding lectures about the sexual reproduction of *Vorticella*, *Gregarina*, *Plasmodium*, etc., on the one hand, and of *Volvox*, *Pleurococcus*, *Spirogyra*, etc., on the other; you will see that there is no essential difference left in the behaviour of their male gametes which all move actively. This is another reason for our scientific conviction that animals and plants must have sprung from common, as yet undifferentiated ancestors; for, widely as the two kingdoms may stand apart, and easily as they may be distinguishable from one another in their more highly developed species, they closely resemble each other, and are even inseparable, in their humblest members (p. 258).

To return to the higher plants, their immobility entails another difference from the animals, which concerns the **natural dispersion** of the offspring. The animals, capable of moving about, can depose their offsprings wherever they like, and the young, again, can spread so far as the conditions of the environment permit. The seeds of a plant, on the contrary, can but drop to the ground, and if germinating there, will find a gradually increasing number of mates, each of which is compelled to struggle for its existence with all the others. It is evident that such conditions are incompatible with the inherent bent of every organism to propagate its race and to gain ground. The higher plants, as a matter of fact, also manage to do so by dispersing their seeds; but, being themselves rooted to one spot, again resort to external agencies for the purpose. The devices they adopt are varied and in some cases most interesting; the Flora (see note †, p. 321) of Egypt does not unfortunately afford very instructive instances, but a few may be mentioned.

Among the agents which distribute the seeds of plants, wind and animals again rank first, and on the parts of the fruits, or seeds, call forth adaptations similar to those we found in the anemophilous and entomophilous flowers. The pods of the Lebbakh, for example, are very thin and light, and remain on the trees without opening until the warm and dry spring-winds carry them off, while at the same time causing them to burst and deliver their seeds. These pods strewn about give an almost characteristic aspect to the streets of this town after any strong khamsin-wind. In other plants such as the yellow-flowered *Bignonia gracilis* (occasionally met with in gardens) the seeds develop large membranous expansions, similar to wings, which are obviously destined to make their owners drift before the wind, and, probably, even to prevent them from falling directly to the ground from the mother-plant. In place of the wings, we often find crowns of thin, light hairs, which make the seeds float in the air after the fashion of feathers.

The dispersion of seeds by animals is effected in two somewhat different ways. If they are contained in fruits the " flesh " of which serves as food for animals they are carried away with the fruits to one place or another and remain behind when the fruits are devoured. Not infrequently, they even pass through the digestive canal of the animals without loosing their vitality and —a very suggestive fact—in a few positively established cases even gain in vitality, i.e. germinate more easily, after a passage through the intestine of animals; This is one way in which seeds may become dispersed by animals (including Man); in order to see how the principle works in the case of date-stones, melon-seeds, orange-pips, etc., you only have to look about you in the streets when the respective fruits are in season.

The other way is realised in seeds or fruits which on their surface develop hooks, thorns, and similar contrivances for attaching themselves to the skin of animals; being thus taken away from their birth-place, to be wiped off at some possibly distant locality. Among the various species of plants which inhabit the fallow areas along the borders of the desert there are several which show this peculiarity, as you may easily verify from the aspect of your trousers after having taken a walk over such a piece of ground. Many of these seeds, be they dispersed after one method or another, of course never reach places where they can germinate and yield new plants. But this is of no matter, as all the species concerned have adapted themselves to the conditions and meet the inevitable loss by the production of a superabundance of seeds.

While the methods of distribution thus far mentioned are passive, a small number of plants adopt active means for spreading their seeds. The fruits in these cases develop an internal tension which eventually results in a kind of explosion by which the ripe seeds are flung out for considerable distances. The Flora of Egypt, so far as I am aware, does not afford an example of this interesting variety of seed-dispersion.

We have on the preceding pages only spoken of the sexual reproduction of the higher plants. From the animals and the lower plants, we know that, besides this, there exists an **asexual reproduction** by division and budding. While the higher animals have become entirely unable to multiply in this way, the capacity is widely spread amongst, and plays an important part in the life of, the higher plants, in which it is also termed "**Vegetative**" **Reproduction.**

Among the various means by which it is accomplished we may first mention the so-called "**Runners**". You may see them, e.g. in the strawberry (*Fragaria vesca*, شليك or فرولة), which is now generally cultivated in Egypt, and supplies one of the most instructive examples of this form of reproduction. The runners are special shoots which, keeping near the surface of the soil, remain entirely bare for ten to twenty centimetres (or even more) and then from one point produce a small bunch of leaves, which after a while develops roots of its own and finally becomes an independent plantlet by obliteration of the runner which thus far connected it with the mother-plant. In this way, an original individual, if undisturbed, may spread over an ever increasing area of ground by a form of multiplication in which flowers and sexual cells do not concur.

In the strawberry the runners lie on the surface of the soil; there are, however, other plants in which similar structures develop subterraneously, and then assume the general appearance of roots, an appearance which in fact often causes them to be taken for true roots. Their internal structure, however, if properly investigated, and the presence on their surface of small scale-like leaves with buds in the axils frequently observable, reveal them to be underground stems, so-called "**Rhizoms**"*: They have the special function of producing, from the buds mentioned, new shoots which emerge from the ground as apparently independant plants. While these latter, together with the mother-plant, usually die with the end of the summer the rhizoms remain alive for years and supply new plants every spring. They do the same when the older shoots are for some purpose cut by Man, as is done for instance with the sugar-cane, the bamboos, and the various forms of reeds growing in this country. These plants (and others as e.g. the Banana) possess rhizoms, and the constant production of new shoots in place of the older which die, or are artificially removed, is a form of vegetative multiplication.

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* From the Greek ῥίζα—see note *, p. 75.

The rhizoms, as they remain alive in the ground for many years, are perennial, and in this respect differ from similar structures which we distinguish by the name " **Stolons** ". These are found, among others, in the potato-plant. If we examine a specimen of this, carefully unearthed towards the end of the warm season, we will find, besides its ordinary, irregularly branching roots, other filaments which somewhat deviate from the usual appearance by being of about uniform thickness throughout, by having few or no lateral branches, and by carrying near their ends the well-known tubers. These filaments are the stolons, and therefore no roots proper, but underground stems, the chief function of which is, not to absorb food-materials, but to produce the tubers. The latter, as anticipatingly mentioned on page 344, alone remain alive in the ground, while, with the end of the warm season, the stolons perish, together with all the rest of the plant, and therein differ from the rhizoms, but resemble the runners.

The **Tubers** produced by the stolons are, scientifically considered, underground shoots with shortened but powerfully thickened stems. You are familiar with their appearance from the potatoes. Their most important peculiarity is their possessing a number of "eyes", which are in reality small buds, in essence the same as those we find in the axil of every leaf on the ordinary above-ground stems, and like these capable of growing out into new shoots. The rearing of the potato in practice is carried on in this way that a tuber, instead of being employed as a whole, is, for economy's sake, cut into a number of pieces, each with at least one bud. These pieces are placed in the earth, bud upwards, and give rise to new plants, which form their first leaves at the expense of the reserve-starch stored in the tissue of the tuber (p. 333), and from the surplus they assimilate in later life produce up to a dozen or even a score of new tubers near the ends of newly formed stolons. So the formation of these tubers is a method of asexual or vegetative reproduction.

There still exist other methods, all more or less interesting, but the few examples quoted may suffice to show you the general aim of the vegetative multiplication, and the most conspicuous means by which it is effected.

In the animals, we saw that the asexual reproduction very often occurs in more or less regular alternation with the sexual, the whole life-history of the respective organisms then assuming the form of heterogenesis. We find absolutely similar conditions in a number of plants (e.g. the Ferns; details cannot here be given); in the greater majority, however, especially in all higher plants, sexual and vegetative reproduction occur side by side and without regular alternation. In a small number of plants cultivated by Man for centuries back the latter method has even gained such a preponderance that it seems to practically suffice for the preservation of the race. An instance of this sort is, among others, presented by the Banana which, though forming flowers and fruits, does not produce any normal seeds and is multiplied exclusively by new shoots from its rhizom.

Facts like this, in connection with what we learned about the life-history of the Bacteria (p. 305) seem to disprove the truth of the general rule emphasised on previous occasions, namely, that any organism, in order to fully retain its properties and vital energies, must, at one time or another, enter into sexual relation with a second individual of its race. I say " seem to disprove " because, if we review the situation critically, we perceive, first, that the above rule is absolutely true for all the hundreds of thousands of typical animals ; since, further, among the plants also, the few cases like that of the Banana disappear, so to speak, among the number of those species which manifestly require sexual reproduction, there can be no doubt but that we have here to deal with exceptions to the rule, perhaps just those exceptions " which confirm the rule ". The regular production of flowers and sexual cells by the Banana (and the few other plants which do not seem to form normal seeds) at any rate indicates that these organs must have been necessary to the ancestral generations of the actually living specimens, and if they seem to have for some special reason become dispensable this is not at once a proof against the necessity of the sexual reproduction in general. Nor can it even be considered as perfectly established that the Banana (and its associates) multiply vegetatively for ever ; for the possibility exists that they may form seeds under special conditions of which we are as yet ignorant, or that seeds are only produced at long intervals, etc.

Be that as it may, there certainly are other plants of practical importance, and carefully studied on account of this importance, which very ostensibly show that an artificial propagation by mere vegetative means within comparatively short periods leads to a deterioration of their quality. One of the most striking examples of this sort is supplied by the potato. I have already described the method by which it is practically cultivated (p. 382), but what was said there is not the entire life-history. Besides the tubers, the potato also produces flowers and seeds which latter, when sown out, develop into plantlets which remain small during the first year of their existence and not till the second form both seeds and tubers (the potato therefore is "biennial", as we previously saw of the beet; p. 343). The practical experience gained by farmers now agrees in showing that any variety of potato, if solely propagated by tubers, after an average of ten generations distinctly loses in the quality, the size, and the number of the new tubers it yields; in other words, that the mere vegetative multiplication is not capable of maintaining the original properties of the variety for more than a limited lapse of time. If on the other hand the plants reared from such deteriorated tubers are allowed to form seeds, the individuals developing from these in due time produce tubers which in addition to their original qualities have gained new reproductive power and satisfy the practical demand for about another ten generations. The "rejuvenating" influence of the sexual process, in cases like this, is striking.

When new potato-plants are reared from seeds it is found, further, that the descendants even of one and the same plant are not all alike but differ in various respects, among others in the properties of their tubers. By selecting variations which appear to be good, and allowing them to form seeds, new "varieties" or "races" of potatoes are obtained, and it is a peculiarity of the sexual process to yield them. For the individual seeds contained in a potato-fruit, though all originating from egg-cells of the same plant, have yet been fertilised by pollen which is derived from different plants, and may accordingly be the bearers of different biological qualities. In the tubers which are produced by one individual, without the intervention of a second, such a thing is impossible, and so the formation of varieties is an exclusive result of foreign pollination. The plants therefore behave exactly as do the animals in which, as we saw on page 169, foreign fertilisation and (where this is possible) hybridisation are employed in practice for obtaining new races, in one respect or another superior to the natural individuals. The same is done with plants, but it is clear that all our efforts in this direction, which at present mainly depend on empirical experience, might probably be conducted more purposefully if we knew exactly the laws which govern the transmission of parent peculiarities to the descendants.

Apart from the practical side, the problem also presents an uncommon interest from the purely scientific point of view, and it is therefore not surprising to see that biologists have, for long and from various sides, attempted its solution.

CHAPTER XIII.

The Mendelian Laws of Heredity.

The results obtained by the investigation of the minute phenomena connected with nuclear division and sexual reproduction no longer leave any doubt as to where we have to look for the substantial agent of inheritance; it is the chromatin or idioplasm (p. 184) of the nucleus. The question how individual peculiarities of the parents are transferred to the descendants has recently received a satisfactory answer from the experiments of GREGOR MENDEL, of Brünn, Austria. Though first published in 1865 and 1869, they remained unheeded until several investigators, independently from one another, returned to the subject about a dozen years back and "rediscovered", so to speak, the facts first established by MENDEL. The natural laws unveiled by these researches are at present combined under the name of the "**Mendelian Laws**", while the phenomenon itself which within the short lapse of a dozen years has developed into a prominent department of biological research is called "**Mendelism**". Owing to the great general interest the Mendelian Laws offer I will here try to explain to you their principle; for doing more than this a discussion of details would be required which lie beyond the range of these lectures.

We know that any descendant of a pair of parents not only shows their general structure and appearance but may often, and seemingly at random, also exhibit quite insignificant details present in one of the parents. The success obtained by MENDEL was the outcome of an ingenious idea of his, namely, to select for his first experimental studies as to the principles, according to which the properties of the parents might be transmitted to the offspring, parental individuals which just differed in one minor detail. So he chose, among others, two varieties of peas, one of which had a tall, the other a short stem; or two other varieties, one of which produced rounded, the other wrinkled seeds. Later investigators, working with other plants, and some with various animals, not only fully confirmed Mendel's results, but also established the perfect correctness of the explanation he had given of the phenomena observed. Instead of going into details of these experiments I will here relate, in a generalised form, what they have taught us about the rules by which the transmission takes place.

The biological peculiarities of an organism we know are determined by its idioplasm (p. 184). Supposing that there existed two absolutely identical individuals of a species they would possess identical idioplasms in their germinal cells. These idioplasms would not be materially altered by the reduction-division during maturation, and so, by uniting in copulation, would yield identical descendants, in the first as well as in all subsequent generations. Supposing, on the other hand, that two specimens of a species differed just in one character, having, for instance, a certain part coloured black and coloured white respectively, and having, in addition, each inherited its particular colour from both father and mother, then we may assume that the germinal cells of these two specimens differ in that the idioplasm of one contains the factor black (●) at the place where the idioplasm of the other contains the factor white (○). In the immature germinal cells, these factors will appear in the shape ●● (viz. ● from the father and ● from the mother) and ○○ (○, again, from the father, and ○ from the mother). During maturation (see p. 115f and p. 117f), both are first halved to ⯊⯊ and ◠◠, and, by the reduction-division, subsequently reduced to ⯊ and ◠. In this form, they will meet in the fertilised egg-cell; since, however, we know that the constituents of the nucleus restore themselves quantitatively before a new division occurs, the two half-factors ⯊◠, also, may be assumed to restore themselves to ●○, probably even previous to the first division of the fertilised egg-cell. They will, in this shape, be handed down to all the body-cells of the descendant which develops from the egg, and will, in the idioplasm of the descendant, appear at the place where the parent idioplasms had ●● and ○○ respectively.

From the experiments made, it appears that this change in the idioplasm of the "cross-bred", as the descendant is technically called, may manifest itself in two different forms; in a simpler case, it becomes visible inasmuch as the cross-bred exhibits the mixture; for instance, in the case above assumed, appearing grey where one of the parents was black and the other was white. In the other case, the cross-bred does not show the mixture, but appears black or white, according to whether one factor, as we put it, is "**dominant**" over the other which is "**recessive**". Though this latter alternative seems to be the more common, we will first consider the former as it is more easy to understand.

The germinal cells which develop in the cross-bred, as we pointed out above, each contain the factor ○● instead of the simple ●● or the simple ○○ of the parents. During maturation, we know that ●○ will first be split into two ⯊◠, and that one half of each of these ⯊◠ will ultimately remain with the mature germinal cell. Now the Mendelian experiments leave no possible doubt that this remaining half may be either of the original constituents of ⯊◠; in other words, that the differential characters of father and mother, combined in the immature germinal cells of the cross-bred, "**segregate**" again during the maturation of these cells; thus leaving an average half of their number with the factor ⯊ and the other half with the factor ◠ (as these are subsequently both restored to the full quantity we may, for simplicity's sake, at once return to the signs ● and ○ for indicating them). Each cross-bred, therefore, will, in contrast to the parents, form two varieties of germinal cells, one variety containing the factor ● and the other the factor ○; and when two such individuals are mated 2×2=4 combinations of these germinal cells are possible. Indicating the male cells by ●♂ and ○♂ and the female cells by ●♀ and ○♀, these combinations are ●♂●♀ ●♂○♀ ○♂●♀ and ○♂○♀; among every four of the descendants which develop from these unions there will therefore be one which only contains the factor ● and one which only contains the factor ○, while the two remaining still contain both ● and ○ mixed.

If expressed in plain words this means that cross-breds, copulating among themselves, again yield individuals of the **pure parental forms** which, as they only have, one the factor ● and the other the factor ○, must each breed purely in all further generations; that is, ●, if copulating with its like, will thence onward only produce an offspring with the character black, while ○, under the same presupposition, will invariably produce descendants with the character white. The two combinations ●♂○♀ and ○♂●♀, on the other hand, if paired among themselves, will again behave as described, that is, being cross-breds, they will in every subsequent generation split anew according to the formula $\frac{1}{4}$●, $\frac{1}{4}$○, and $\frac{2}{4}$●○.

Let us now consider the second case in which one character, as we said, was "dominant" over the other. If we assume that this be ● then the offspring produced by the parents ●● and ○○, though containing ●○, will **appear** black because ●, as it is "dominant", covers ○. It does so whenever it comes together with it, and so the descendants of these cross-breds will no longer present the above picture ♂●♀●, ♂●♀○ ♂○♀● ♂○♀○, but ♂●♀● ♂●♀◍ ♂◍♀● ♂○♀○; that is, we find here among every four of them one of the pure parental form with the recessive character ○, and three with the dominant parental character ●. It is, however, clear from the first formula that only one of these three is actually pure with regard to the factor ●, while the remaining two are mixtures in which ● hides ○ as indicated by ◍. That this is so is proved by the descendants which arise when these black cross-breds are mated among themselves. For it is then found that only one-third of their total number give purely black descendants in all further generations while two thirds, namely, the combinations ♂●♀◍ and ♂◍♀● split as before.

It has already been mentioned that Mendel's original experiments have in recent years been repeated with numerous animals and plants by different investigators; the results proved to be the same with astounding regularity, so that there is no doubt that in the "Mendelian Laws" we have indeed to do with natural **laws.** They are easily comprehensible in cases like those above described, that is, when the original subjects of the experiments only differ in one property. But such cases are not of frequent occurrence in nature, where, on the contrary, we find paternal and maternal individuals usually differing in several, and often even in many details. The experiments made have shown that the principle of transmission remains the same even then, but that the complexity of the results increases in geometrical progression. To specify this a little further, the number of varieties of germinal cells produced by a cross-bred rises to 2×2=4 if its parents diverge in two kinds of characters (in one particular case, these were, e.g. the colour and the shape of the seeds); these four varieties of germinal cells, if they meet during fertilisation, are able to give sixteen combinations of seed-colour and seed-shape, among which one-sixteenth will again be the pure paternal and one sixteenth the pure maternal combination, while all the rest are mixtures, though some of identical composition*. If there

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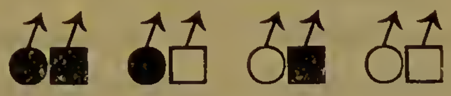
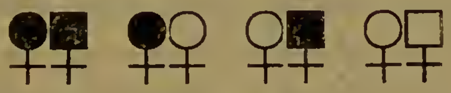
* You may see this from the following graphic picture. Indicating the two differential characters by ring ○ and square □, and differentiating these by black in the father (●■), by white in the mother (○□), they combine in the cross-bred into ●■○□, but are by the "segregation" during the reduction-division separated into the four varieties :—

●■ ●□ ○■ ○□

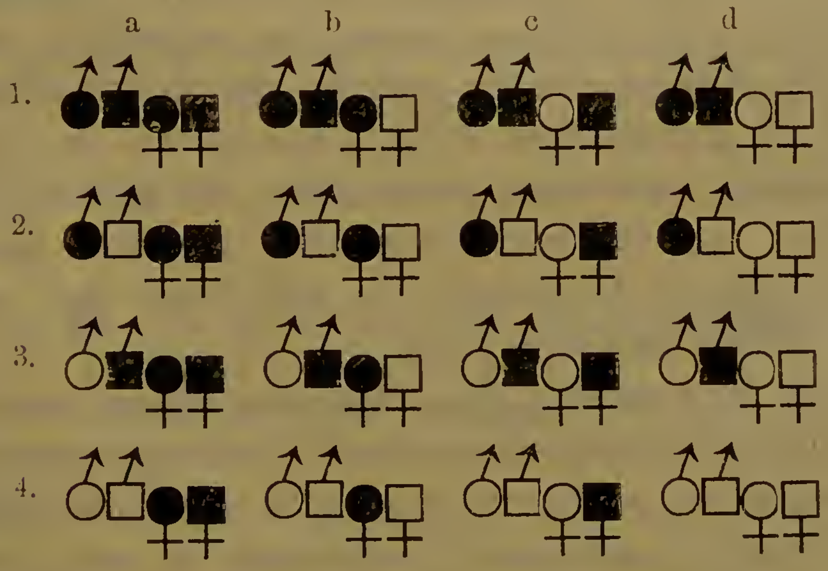
If two such cross-breds are mated the father contributes the spermatozoa :—



the mother the egg-cells :—



These can copulate in the descendants in the following combinations :—



We here see that 1a and 4d are again the pure grandpaternal and grandmaternal forms, as they solely contain the factors black ●■ and white ○□ respectively. Substantially similar are 1b and 2a; 1c and 3a; 1d, 2c, 3b, and 4a; 2d and 4b; 3d and 4c; for they actually contain the same factors, only that in one case these are of paternal and in the other of maternal origin.

are three kinds of characters in which father and mother differ their children will possess 2×2×2=8 different varieties of germinal cells which in a second generation will form sixty-four combinations, and among these one-sixty-fourth will be the original paternal and one-sixty-fourth the original maternal combinations. You thus see how intricate matters become with the increase in the number of differential characters; ten such distinctions would result in the child forming 2×2×2×2×2×2×2×2×2×2=1024 varieties of germinal cells which in a second generation would be able to combine in 1,048,576 different manners; and yet ten differences between parents is not by any means an unusual variation.

Under these circumstances it is comprehensible that e.g. human individuals are practically never absolutely alike; for it results from the above deductions that a pair of parents differing e.g. in the colours of their hair and eyes and in the form of their ears, that is, in three kinds of properties, would have to produce sixty-four grand-children before the probability arises that one of these is again exactly like its grandfather or like its grandmother with regard to the three particulars; and when grandfather and grandmother differ in ten characters more than a million grand-children would be required in order that the same result should then take place.

In all the remaining descendants the original paternal and maternal characters are mixed in various proportions and, what is particularly worthy of note, are mixed, in a definite percentage of individuals, in such a way that special grandpaternal or grandmaternal characters are entirely eliminated from the idioplasm. We may observe this even in our simple example above given (p. 389); for one quarter of the grand-children have nothing left of the grandpaternal ●, and another quarter nothing of the grandmaternal ○*.

This fact is of particular interest from the medical point of view, since predisposition to some particular disease or defect may figure among the differential characters. The corresponding anti-character will be non-predisposition, i.e. health, and will in the main also be dominant over its antagonist. It has for long been known that such a predisposition to certain diseases or defects is transmissible, and is especially likely to be inherited when both parents already possess it in their ancestry. But it is also known that despite this circumstance the individual descendant does not of necessity inherit the disease or defect. The Mendelian Laws afford the explanation for these empirically established truths. The children of a pair of parents, one of whom is affected (let us assume the morbid factor be ● in the above example), while the other is not (○ in the example), will all have ●○ in their idioplasm. If two persons of this description marry there is the mathematical probability that among every four of their children one is again entirely healthy $(\overset{♂}{○}\underset{♀}{○})$, while the three others possess the predisposing factor ●, and one of them even doubled $(\overset{♂}{●}\underset{♀}{●})$. The chances for this latter are of course bad; but the others $(\overset{♂}{●}\underset{♀}{○})$ and $(\overset{♂}{○}\underset{♀}{●})$, supposing that ○ is dominant, may escape, i.e. remain healthy despite the presence of [illegible] in their idioplasm. If individuals of this description again marry the previous process will become repeated, that is, among every four descendants one is likely to be entirely free from the morbid factor, while three still have it, and one even from both parents. So we understand that children of parents who are apparently quite healthy personally, but have the factor in their ancestry, may, and in particularly unfortunate cases even must, again fall victims to the disease or defect.

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* The same is evident from the instance given in the note on page 391; on reviewing the sixteen combinations you will see that, e.g. the grandpaternal ● is absent from all combinations with the numerals 3 and 4, that the grandmaternal ■ is absent from all combinations with the letters b and d, and so on.

If this consequence of the laws of heredity is depressing in one respect, it is comforting in the other that a number of the descendants are sure to lose the predisposing factor altogether. The truth of this consequence is borne out by facts in so far as mankind, notwithstanding the constant inter-marriage of individuals, still counts in its midst a good many healthy representatives, while otherwise diseases, the predisposition to which is capable of being transmitted to the offspring, would be much more frequent. On the other hand, the Mendelian Laws also clearly show the danger which arises for the offspring from continued inbreeding (p. 158).

In the preceding discussion I have assumed, for simplicity's sake, that health and predisposition to disease are the only differential characters between parental individuals. In reality, conditions increase of course in complexity commensurately with the increase in the number of the distinctive factors ; but the principle of their transmission remains unaltered.

In addition to the light the Mendelian Laws throw on facts already known they also prove that the union of different parents may, from the third generation onwards, yield combinations of characters which did not exist before. Supposing that the respective individuals are capable of living and reproducing themselves—which we know is often not the case—they may be useful for the aims of Man in one respect or another. Every now and then, however, we may read that the Mendelian Laws, if properly applied in practice, might even bring about a material improvement of the human and the animal races as such. It is to be feared that this hope will be disappointed; for all the facts thus far established concordantly indicate that hybridisation may yield new combinations of already existing characters, but that it is not capable of creating new characters.

CHAPTER XIV.

On the Structure and Development of the Metazoa.

The Doctrine of Evolution.

There now remain for a brief discussion the multicellular animals or Metazoa (see p. 60). I may here first mention that besides the "recent" Metazoa, i.e. those which at the present period populate the earth, we know of a great variety of forms which lived in earlier epochs of the earth's history, but have since then "died out", or "become extinct". By far the greater number of the individuals of these forms have perished and disappeared without leaving trace of their existence; not infrequently, however, particular circumstances, such as volcanic eruptions, great inundations, small local catastrophes, etc., led to a more or less sudden enclosure of specimens in earth or mud, and in this way to a preservation of their bodies. While the soft parts of the latter decomposed gradually even under these conditions, and are at the present time probably reduced to mineral oils and similar substances (see p. 272), any bony or chitinous skeletons, or any shells the specimens may have possessed remained intact within the enclosing material, and thus enable us even to-day to form a fair idea of the shape and part of the organisation of the respective creatures. The study of these "**fossil**" or "**petrified**" organisms is the object of a special science called **Palaeontology***; it has shown, among many other interesting facts, that certain recent animals are found in a fossil state even in very deep and old layers of the crust of the earth, i.e. must have lived and propagated their race without noticeable changes through millions of years, while by far the greater number of the fossil species more or less differ from the recent ones, but represent unmistakable and often most instructive connecting links between other forms, fossil or recent, which in shape and organisation seem to stand far apart. Instances of the latter description supply some of the most convincing proofs in support of the doctrine that the entire series of organisms which live, and have lived, on the earth, are the result of a gradual evolution from a simple to an ever more perfected and complex state.

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* Greek; from παλαιός—old.

On looking at the world of organisms with an unprejudiced eye we are indeed forced to the assumption that a tendency to progress and perfection must be innate in the living substance itself, and connected with the very life of every organism. It may not show itself for many generations in certain species, and may even be entirely absent is numerous others, but it is certainly present in the world of organisms as a whole. It will help you to understand what I mean if we look at the example of the highest organism, namely, Man himself.

There are perhaps few people on earth who are really content with the lot that has fallen to them; the great majority try to " get on ". Large masses, unfortunately, have actually to fight for their bare existence; but even of those who are not at all badly off, many, according to their more materialistic or more idealistic disposition of mind, suffer from a craving, conscious or instinctive, to increase their wealth, or to better their position in some less prosaic respect. The desire to " get on " is general; it is the "struggle for life" in its various (justifiable or unjustifiable) aspects. The weapons used in this struggle are manifold;

they may be fair, consisting in earnest labour, in honest exertion of all physical and mental faculties, in clever utilisation of given conditions ; but they may also be unfair and in a strange contrast to the exalted position which Man is so fond of claiming for himself; lying, cunning, deceit, forgery, and violence being in fact the expedients by which a good many people try to insure their progress towards success. In any given case, and whether the weapons used be right or wrong, the one who is the "fittest", i.e. who, in the particular case, proves to be the cleverest, or the strongest, will carry the victory over his competitors, but will, on the other hand, hold his position so long only as he actually remains the cleverest or the strongest. This struggle for existence, the necessity, or the mere instinctive desire, to outdo the others, although it is in our days undoubtedly more intense than it was before, has existed as long as the human race, and the result is that the Man of the present day, if considered as a whole, is farther advanced, both with regard to his good and his evil qualities, than was his ancestor of former centuries.

What we observe in the human individual is even more conspicuous with reference to whole nations and races. These also have to fight for their existence, and it is the "fittest" which will "survive"; but will survive only so long as it remains the fittest. We see from history how nations, often small, suddenly came to the front, owing to the moral and physical virtues of their citizens, how they gradually conquered and assimilated other nations and went through a flourishing period, but eventually went down again in the measure that their original virtues relaxed. Their empires fell to pieces, and while some of the constituent parts declined further and finally, either altogether lost their national or racial independence, or succeeded in maintaining a modest existence in some secluded corner of the earth, others developed to new strength and power and saw new periods of splendour, followed by times of decadence. There has been a continuous waving up and down; but, here again, we see that Mankind, if considered as a whole, has made distinct progress, while its different constituent parts took a different share in the process, some parts changing to a greater or lesser degree, or even entirely perishing in it. The "struggle for life" among the nations and races of the earth is at present also more lively than it was in former times; but whenever a nation or a race becomes involved in it, it must exert all its moral, mental, and physical capacities in order to become, and to remain, the "fittest"; otherwise its fate is sealed beforehand. This has been so since the beginning of Man's history and will be so until the end.

It is so also with regard to the various communities of organisms, with the only difference that what in human history we see displayed within the lapse of a few centuries in the organisms requires infinitely longer periods. But Palaeontology irrefutably shows that in the earth's history organisms have over and again arisen, more perfect and more highly developed than those which existed before, that these new forms, after having spread over large areas and flourished for a period, again declined, new and better equipped forms occupying their place, while the original species, unable to maintain themselves in the competition with these fitter rivals, gradually died out, or, in some instances, still form small, but fairly isolated communities in the present world of organisms.

A very interesting example of these gradual changes is again supplied by our own race; for Palaeontology shows that the species *Homo sapiens* has not always been exactly the same that it is to-day. In the history of Man, we usually distinguish a "historic" from a "prehistoric" period; the former being reckoned as far back as we possess written documents (on paper, or carved in wood or stone) by which the people of the respective time left notice of their doings, their laws, their creeds, and so on. This period comprises several thousand years but, as the documents in question become the scarcer the older the time, it is clear that there is no sharp limit between the historic and the preceding prehistoric period. Within this latter, two principal sections are distinguishable; there is a more recent section of which we also possess proofs of Man's existence in the shape of buildings, weapons and tools made by his hand, but no longer any documents in writing. Frequently even human skeletons, entire or fragmentary, have been found (among other countries in Egypt and Nubia), and it is a remarkable fact that they in no way essentially differ from the skeletons of the Man of the present day.

But there is still the earlier prehistoric period in which Man had apparently no knowledge yet of making tools, because no such tools have ever been met with besides the skulls and other bones which in various localities (e.g. of Austria, Belgium, England, France, Germany), were incidentally discovered, embedded in deep layers of the soil, together with the remains of animals at present extinct. The skulls in question, on the one hand, leave no doubt that they are human, but, on the other, exhibit characters (such as inferior cranial capacity, flatness of the roof, strong projection of the superciliary arches, reduction of the chin, and others) which have disappeared in the recent Man, but are still observable in the "anthropoid"* or Man-like apes. These differences, confirmed over and again by scientists of authority who critically examined the relics, led to the distinction of the "*Homo primigenius*" as a distinct ancestral form of the recent *Homo sapiens*; they prove that our forefathers had "simian* characters", and indicate that in bygone times Man and the anthropoid apes, though different even then, yet were not so different as they are at present. But while the apes, in the subsequent generations, gradually declined further so as to be at present on the point of dying out altogether, Man conquered and developed into the dominating creature he actually is.

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* From the Greek ἄνθρωπος—Man.

Considered from the palaeontological point of view, Man is a "young" species, i.e. one which made its appearance only in a comparatively late epoch of the earth's history. Other species are much older, and in the case of some of these, we actually know, from their petrified remains, quite a number of ancestors, each of which in its structure represents a connecting link between the earlier and the later form, while the whole series establishes an almost uninterrupted transition from the living species to others with which at first sight it seems to have little or no close relation. In this way, the ancestors of the horse, for instance, connect it with the tapirs, the rhinocerosses and the elephants, that is, with species which outwardly show little resemblance to the horse, but are nevertheless its nearest relatives among the actually living animals.

Thus every organism has its "pedigree"; we scientifically call it "**Phylogeny**"†, and the history of the gradual evolution of a certain organism from differently organised ancestors is the "**Phylogenetic Development**" of this organism. Since Palaeontology is able, in many cases, to throw light on this phylogeny, or to test conclusions referring to it drawn from other facts, it becomes an important and highly attractive part of Biology in the widest sense of the term.

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* From the Latin "simia"—ape.

† Greek; from φυλή—tribe, race, set; and γένω—old word for: to be born, to arise, from which also γενεά (note *, p. 53) and γένεσις (note *, p. 114), are derived.

If we accept as true the doctrine that the recent world of organisms is the result of a gradual evolution from ever more simply built ancestors we are logically led to the conclusion that, ultimately, even the largest and most highly developed Metazoa of the present day must have derived their existence from Protozoa or, at any rate, from unicellular stages. The phylogeny of every species, consequently, would have the cell as its point of departure; it we duly remember this consequence it cannot appear a mere accident that the development of the individual—in the scientific language the "**Ontogeny**"*—of every species also starts from the cell, namely, the egg-cell; we have already emphasised this point on page 43. With regard to their general outlines there is thus an unmistakable parallel between the phylogenetic and ontogenetic histories; but there is more. A considerable number of facts fully ascertained in the course of time prove that, between ontogeny and phylogeny, there is even agreement in certain essential details. Thus, to mention a few points, it has struck observers for more than a century back that higher animals during their early or embryonic development pass through stages which resemble the definitive stages of other, lower animals; when in the body of an animal malformations of one organ or another occur these often take the shape of the same organ in an earlier state of its developement, creating the impression that it had been prematurely arrested in its formation; on the other hand, organs often begin to develop in the embryos of certain animals, although they are of no use for, and practically absent in, the adult stages, but are fully formed in the ancestors of the respective species.

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* Greek; from ὦν, ὄντος — the same as the English "being".

We shall return to some of these facts in more detail later; taken in their entirety, they have led to the conception of what we call "the **Fundamental Biogenetic Law**"; this says that "the ontogenetic development of every species is an abbreviated repetition of its phylogenetic development"; in other words, that the various stages through which an organism at present passes during its individual development from the egg-cell to the definitive form, are in principle the same as those through which the ancestors of the species successively passed, while rising, during the long periods of the earth's history, from the unicellular to their actual state. Whether we call this conception a natural law or a mere theory, it certainly makes it comprehensible that many Metazoa, widely as their adult stages may differ in shape and internal structure, yet during their embryonic development show phases which, apart from secondary and often very conspicuous modifications, are the same fundamentally. This likeness forcibly suggests a natural relationship; but since it only occurs in the earliest period and becomes more or less effaced during later life, so it must also be assumed that the relationship of the respective creatures was closest long ago, that is, in their early phylogenetic history.

In order to get an adequate idea of these conditions we may again refer to the example of our own race as an illustration. It is a fact of frequent occurrence that human families, although they derive their origin from one common ancestor, yet in the course of time split up into several lines and branches, among which the relationship is less close, and will grow ever looser in the generations to come. There are also plenty of examples showing that one of these branches rose to prosperity or power while the others, less gifted perhaps and less clever, remained on their original level or even declined, and became thus separated from their relatives by more or less marked differences in social position. In other cases, when the descendants care nothing, or have no reason to care, for their "pedigree", they soon lose the remembrance of their common origin, and after a few generations are entirely unconscious of their relationship which remains only indicated by the common family-name, or, every now and then, by "family-resemblance". As in these cases the relationship, though forgotten and, perhaps additionally obscured by differences in social position, is yet proved by history, and occasionally recalled by certain outward signs, so the likeness in the early development of certain organisms is a kind of historical proof that once upon a time their ancestors were nearly related, even when the descendants subsequently separated and, going each its own way, appear totally different and foreign to one another in their present condition.

If combined into a whole, the biological and palaeontological observations at present at our disposal suggest the following main picture of the gradual evolution of the animal kingdom. Its first representatives which arose were of the simplest nature. After a longer or shorter period, some of them, owing to the tendency to perfection innate in the living substance, assumed a more complicated structure, while all the rest remained in their original state and so propagated their race, until one part succumbed in the struggle for life against stronger rivals or unfavourable conditions, whereas another part succeeded in maintaining themselves and so still are members of the actual animal kingdom. The same in principle subsequently happened to the new and more perfected forms. They first spread and went through a period during which they flourished, but eventually declined, the result being the springing into existence of new and again more perfect forms, while the less fit either died out or lived up to the present epoch. The process here outlined became repeated over and again during the various periods of the earth's history, and thus it results that, on the one hand, the present animal world is composed of creatures showing all those different degrees of perfection we observe between the Protozoa and the highest Vertebrates, and that, on the other, even the latter, during their ontogenetic development, still more or less clearly recall the fundamental characteristics which their ancestors possessed long years ago.

If in this way we establish a parallel between the ontogenetic and phylogenetic histories of the various organisms this must not be understood in the sense that the egg-cell of e.g. a higher Metazoon is still virtually and materially the same as the Protozoon from which the Metazoon derived its origin. We have already emphasised on page 46 that the living protoplasm, although we cannot differentiate it by our methods of observation, must yet be different in different organisms; that in fact there must be as many varieties of protoplasm as species of organisms live, and have lived, on the earth. Thus, the body-substance of a Protozoon is protozoan protoplasm to-day, as it was protozoan protoplasm millions of years ago, and when in the course of time some Protozoa succeeded in acquiring a higher organisation, and thus ceased to be Protozoa, it is a logical necessity to assume that their body-substance also ceased to be of protozoan nature. Only under this supposition is it possible to understand that the new forms were able to maintain their characters and pass them on to their descendants, until perhaps fresh changes in their protoplasm led to the springing into existence of fresh structural types. The gradual advance and perfection in the organisation of the living beings is therefore inseparable from a concomitant perfection of the intimate structure of their body-substance; for there can be no doubt that the protoplasm of an Amoeba, which cannot but again produce Amoebae, must be as many times less complicated than the protoplasm of e.g. a bird's egg-cell which invariably again develops into a bird, as the full-grown Amoeba is less complicated than the full-grown bird.

A comparison, as in former cases, will help you to understand what I mean. We have often referred to the similarity between an organism and a steam-engine. When the latter was invented (by JAMES WATT, about 1770) it was of the simplest structure: within a cylinder, the expanding power of water-vapour caused a piston to alternatively move up and down, these movements, in their turn, being used to make a wheel rotate. The steam-engines of the present day are so infinitely more complex, and are adapted to so many more special purposes than was the original engine that it would have been quite impossible for the first inventor to at once devise so many different and equally intricate mechanisms. Indeed, the steam-engines of the present day have a "phylogeny"; they are the result of a gradual evolution of an originally simple type in which changes and additions were over and again made, now in one detail, now in another, but always with the aim to make the engine fit for a more perfect work. The feature which specially concerns us here is that, together with every change, the general standard of the structure of an engine became raised. As an engineer, to-day, when he devises a new improvement, will not start with the standard of engine of a century ago, but with the latest standard, so we must also imagine that the more highly organised Metazoa, when they commence their development, do not start with the protozoan structure of the protoplasm but with that structure which their immediate predecessors have acquired during their phylogenetic history. And if the organisms of the present day, despite all their diversity in details, evince their common origin by the preservation of certain fundamental structural features, we see the same in our modern steam-engines which, of whatever description they may be, still retain the fundamental working parts of their common ancestor, namely, the cylinder, the piston, and the rotating axis.

Since, according to the picture above outlined, the Metazoa must have once sprung from unicellular animals the question arises whether traces of this transformatory process may still be observable among the recent organisms. In this connection, the multinuclear species, such as *Opalina* (p. 97) and (among the plants) *Botrydium* (p. 266) might first be mentioned. They are practically unicellular, but would at once become multicellular if the cytoplasmic parts belonging to each nucleus were marked off from one another. As a matter of fact, the multinuclear state is often the preparatory step to division (p. 112), or also represents a division which has not come to perfection.

Another transitory phase between unicellular and multicellular organisms might be found in the formation of colonies discussed on page 92; it is suggestive in so far as it shows that the products of the division of a mother-cell may not separate, as they do in the majority of the Protozoa, but remain united. Although this recalls the conditions characteristic of the Metazoa, there is yet an important difference between the individuals of a colony and the cells of a Metazoan. For, in the case of the latter, the descendants of the egg-cell never exhibit any trace of independence ; it is one of the essential peculiarities of the Metazoa that all the cells which may make up their bodies are, as it were, mere servants, the work of which is regulated by the principle of division of labour as we tried to show by the example of the human households and states on page 27. As, in these, the individuals can achieve little separately, but can achieve much jointly, i.e. by adapting their particular work to the interest of the whole, while at the same time doing this work thoroughly and conscientiously, so the cells of a Metazoon form an ideal state in which each individual has its place and willingly does the duty determined by this place ; if for one reason or another it is incapable of properly working the result is invariably an abnormality or a deficiency of the whole organism (p. 42). In accordance with this fundamental peculiarity of the Metazoa, we also see that the descendants of the egg-cell, owing to the working of the principles of division of labour and functional adaptation, become from the very first transformed and arranged in such a manner as to gradually constitute the systems, organs and tissues of the body, as these have been described in an earlier chapter (pp. 23ff). The descendants of a dividing Vorticella, on the other hand, even when they remain united to form a colony, yet all present the characters of independent organisms and, in fact, behave as such if by some accident they become separated from the others (p. 92). If the colony-formation (as we know it, e.g. of Vorticella) is a step towards the conditions of the Metazoa, it is certainly a very elementary one.

However, we know a similar process also from *Volvox*, and in this, as described on page 256, the conditions are much more significant. As a matter of fact, *Volvox* may well be regarded as an intermediary stage between a true colony of unicellular and the body of multicellular organisms; the decisive factor being that certain individuals lose their independence, i.e. their indifferent nature, at an early period, and become instead delegated for a special purpose in the service of the whole.

The chief types of Metazoa which exist and their most important structural characteristics have been given on pages 228ff. As we have seen there, the differences are great; nevertheless, we had already to point out that our scientific views about the phylogenetic development of the whole animal kingdom are to a large extent based on the fact that many Metazoa, however much they may differ in their full-grown forms, yet during their embryonic development pass through phases which are either similar or almost identical. We still have to study some Metazoan Types in more detail; I think it will help you in understanding both their essential differences and their natural relations, if I introduce the discussion with a brief account of the embryonic development. I would, however, expressly point out that only the merest outlines of this can be given.

1. — THE METAZOA-COELENTERATA.

A.—On the Embryonic Development up to the Gastrula-Stage.

(Plate XX).

The successive divisions of the egg-cell, by which it becomes transformed into a multicellular body, are often termed the "segmentation" or the "**Cleavage**" of the egg. It was already pointed out on page 177 that this process is greatly influenced by the amount of the yolk deposited in the egg-cells. We begin the description with the simplest type, as observed in alecithal and other eggs with little yolk.

Here a first division of the egg-cell, initiated, as all the following divisions, by a mitotic division of the nucleus (p. 106), leads to the formation of two cleavage-cells (Fig. 1). These divide again, and their four descendants (Fig. 2) a third time so that eight cleavage-cells arise (Fig. 3). The planes of these three earliest divisions usually stand at right angles to each other and correspond to the frontal, sagittal, and transversal planes of the later organism (p. 231). By fresh divisions which, however, henceforward occur in a less regular sequence, the number of embryonic cells steadily increases while their size diminishes accordingly. The embryo at about this time bears a certain resemblance to the fruit of the mulberry-tree, and hence the stage is not infrequently termed the mulberry- or morula-stage (Fig. 4). While, outwardly, it appears to be solid, it is, when cut into sections, seen to contain a cavity which, small at first, gradually increases in width so that, eventually, the cleavage-cells which by this time have become numerous and fairly small, only form a thin layer all round the cavity. This is the "**Blastosphaera**"[*], or the "**Blastula**"-stage of the embryo (Fig. 5); the wall being separately called the "**Blastoderm**"[†], the cavity "**Blastocoel**"[‡], "**Segmentation-Cavity**", or "**Primary Body-Cavity**" (*BC*, Fig. 5).

Certain lower animals living in water leave their egg-envelopes at this early period, and by producing cilia on the surface of the blastoderm (see Fig. 5, Pl. XXI), swim about, undergoing the subsequent phases of their development as free organisms. This would indicate that in the blastula-stage we see one of the most primitive types of Metazoan structure. It is perhaps more than a mere coincidence that *Volvox* exactly repeats this structure.

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[*] Greek: from βλαστός—germ, and σφαῖρα—ball.

[†] From βλαστός and δέρμα—skin.

[‡] From βλαστός and κοιλός—hollow (see note *, p. 229).

Whether free or enclosed in the egg-envelope, the blastula, almost spherical in shape, after some time transforms into what we call the "**Gastrula**"[*]. It is seen that one half of its wall becomes at first flattened and then bent inwards (Fig. 6, Pl. XX) until, in the end, it lies closely against the unchanged half of the blastoderm (Fig. 7). The embryo thus assumes the shape of a cup or tube, with an opening at one end and a wall made up of **two** layers of cells in place of the one layer of the blastula. The features just named are the characteristics of the gastrula-stage; the cellular layers being respectively termed, the outer "**Ectoblast**" (*Ec*, Fig. 7), the inner "**Entoblast**" (*En*, Fig. 7)[†], while the axial cavity is the "**Gastrocoel**"[‡], or "**Archenteron**" (*AE*) [§], and the pore leading into it the "**Blastopore**" (*BP*) [¶]. Ectoblast and Entoblast are, perhaps, more commonly known under the names "Ectoderm" and "Entoderm" respectively. It should, however, be noted that the latter names were originally employed for designating cellular layers in the bodies of full-grown animals (see, e.g. *Hydra*, p. 414), and that, therefore, their application in the case of early developmental stages to some extent impairs the preciseness desirable in scientific language. In order to obviate this, the above names Ectoblast and Entoblast have been introduced as special terms for embryonic cellular layers, and will be used in this sense in our present discussions.

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[*] Probably diminutive form of γαστήρ — stomach; alluding to the presence in this stage of a digestive cavity.

[†] From βλαστός—see note *, p. 410, and ἐκτός, ἐντός—see note ‡, p. 53.

[‡] From γαστήρ and κοιλός = "cavity of the gastrula".

[§] From the Greek ἄρχι — meaning, in compositions, as much as "original", "primordial", and ἔντερον — see note †, p. 229.

[¶] From βλαστός and πόρος — pore, opening.

In the gastrula, we have the first "differentiation", i.e. the first visible signs that a division of labour has taken place, in the metazoan body. For while the cells of the blastula, save for slight differences in size (see p. 427f), are all about alike, both as regards their appearance and their relative position to one another, conditions have changed in the gastrula, in which we have two distinct varieties of cells, namely, those of the outer, and those of the inner layer. It is not difficult to suggest the particular function these have in the service of the whole ; for the ectoblast-cells, as they cover the body, will have to protect it and to receive any stimuli coming from without, while the entoblast-cells, as they lie within the body, will take upon themselves what we formerly called the "household"-work of the organism; that is, above all, the work connected with the preparation of the food. **Ectoblast and entoblast are indeed the first "systems" of the metazoan body in their most elementaty shape.**

From the fundamental biogenetic law above explained it would result that the early Metazoa had such a gastrula-structure, and that those of them which subsequently acquired a more perfect organisation still pass through the gastrula-stage in their embryonic development, while the Metazoa which did not advance further, either died out in the course of time, or still represent members of the present animal kingdom. Both inferences are supported by actual facts, which thus represent as many arguments in support of the correctness of the theory. So far as the embryonic development of the Metazoa has been thoroughly investigated a gastrula-stage, or at least a stage referrable to the gastrula, has been discovered ; it has been found, further, that all the later differentiations which may take place in the metazoan body originate from one or other of the two layers, which for this reason are also termed "**Germinal Layers**". Many modifications are observable in these developmental processes ; however, before we pass on to a discussion of the most important among them, let us look at those members of the recent animal kingdom which have not advanced beyond the gastrula-stage, i.e. which even as full-grown animals retain the characteristics of this primitive structural type, and thus show that they are capable of living in this form. They compose the "Phylum" which I previously described as Coelenterates (see p. 229): from among its very numerous representatives still in existence we choose as example one of the simplest forms, namely

B.—Hydra.

(Plate XXI).

The name designates a genus (see p. 77) which comprises a small number of species (e.g. the green *Hydra viridis*, the brown *Hydra fusca*, and others), living in fresh water ; unfortunately, so far as I am aware, none are found in Egypt. Externally, *Hydra* looks (see the larger specimen drawn in Fig. 4) like a fine rod about half a centimetre in length, slightly swollen about its middle and attached by one end to some solid object (water-plants, etc.), while the free end shortly behind its apex carries about eight delicate filaments called **Tentacles.** The whole body is extremely contractile and can, on the one hand, be shortened until it assumes the shape of a bowl with a crown of thick knobs represented by the tentacles (the upper specimen in Fig. 4), while on the other it can be stretched, under corresponding reduction of its diameter, to three and four times its usual length, and so can the tentacles. By stretching, fixing the anterior end to some support, then loosening the posterior end and drawing it near the anterior, the animal can change its place in essentially the same way as you may observe, for instance, in leeches (دود الحجامه).

On closer examination under the microscope it is found that on its top, between the roots of the tentacles, the body of *Hydra* possesses a fine opening (*M*, Fig. 1) which leads into a simple tubular cavity terminating blindly at the posterior end ; eight fine lateral branches of this cavity extend through the whole length of the tentacles, as visible in Figure 1, which represents a *Hydra* halved longitudinally and looked at from the cut surface. The opening is the **Mouth**, while the cavity, also called **Enteron**, is the digestive apparatus. The body-wall (see the cross-section, Fig. 2) consists throughout of only two layers of cells, an outer "**Ectoderm**" (*Ec*) and an inner "**Entoderm**" (*En*), separated from one another by a thin, gelatinous "**Supporting Membrane**" (*SM*). All the cells are fairly similar to each other in their general appearance ; those of the ectoderm are smaller, but more numerous than the entoderm-cells and, in accordance with their protective function, bear on their outer surface a delicate cuticle. Since the ectoderm is also the mediator between the organism and the outer world (see above p. 412), it is not surprising to see that, owing to a further division of labour, some of its cells have taken upon themselves a nervous function ; they communicate with one another by fine strands of protoplasm and thus represent a separate, though little differentiated nervous system. Another very interesting part played by certain ectoderm-cells is that of weapons, both for attack and defence ; these are the so-called " **Nettle-Cells** " or " Nematocysts ". They occur especially on the tentacles, usually many close by one another, thus forming small nodules (see tentacles in Fig. 1). Of their structure, I will here only mention that each cell in its protoplasm contains a large cavity, in which a fine hollow thread is densely coiled up, while the rest of the cavity is filled with an acrid secretion ; thread and secretion are shot out as soon as the cell is irritated. How these cells are used by the animal we shall see presently. The entoderm-cells (Fig. 3) are considerably larger than the ectoderm-cells and somewhat vacuolised ; they bear on their free inner surfaces each a flagellum, and in the green *Hydra viridis* serve as abode for numerous specimens of the Alga *Chlorella* mentioned on page 255 ; these are indicated as small dark bodies in Figure 3.

The **movements** of *Hydra* are brought about by fine filiform and contractile outgrowths, starting, two in number, in opposite directions from the base of each ectoderm- and entoderm-cell and lying, all of them, in the supporting membrane (Fig. 2). In an isolated condition, the cells thus present the shape shown in Figure 3. As their fibres have a longitudinal direction in the ectoderm, and run transversely, i.e. in a circular direction, in the entoderm, both sets act as antagonists to each other, just as was described on page 37 of the muscles of the intestinal wall.

Hydra **feeds** on small aquatic animals. If perfectly undisturbed, its tentacles are fully stretched, extending in various directions, but usually dangling downwards. As soon as a small animal, while swimming about in the water, inadvertently touches a tentacle, the irritation causes this, and the other tentacles, to quickly twist round the victim (Fig. 4) and to discharge their nettle-cells into its body which is rendered motionless almost immediately by the acrid fluid. I may here mention in passing that certain near relatives of *Hydra* (so-called "jelly-fish", living in the sea) may after this fashion injure even a man if during a sea-bath he happens to touch one of them. Their nettle-cells are so numerous, and the fluid contained in them is so irritating, that a mere touch produces an intense itching sensation accompanied by reddening of the skin, which may last for several days. We thus see that in the process of feeding the nettle-cells are weapons of attack, while in cases like the one just alluded to they serve as means for defence; for many larger animals which otherwise might have a taste for *Hydra* and its relatives are kept aloof by these unpleasant organs. The prey caught and killed by the tentacles is subsequently drawn towards the mouth and then swallowed into the enteron, where the digestible parts are dissolved, while the indigestible remains are eventually again voided by the mouth-opening.

Hydra possesses no particular organs for respiration and excretion. There is every probability that the body-cells, as they take their oxygen directly from the surrounding water, so also discharge their waste-products into this. With regard to these two vital functions there is therefore as yet no visible division of labour.

Hydra **reproduces** itself both asexually and sexually. Concerning the former mode it may here be mentioned in the first place that the whole animal can divide spontaneously, and usually does so in a transverse direction, more rarely in a longitudinal direction. Both processes go on in very much the same way as we previously described in *Paramaecium* (transverse division) and *Vorticella* (longitudinal division); the most noteworthy feature being that, here also, the division is associated with a "regeneration", in each daughter-individual, of those parts of the body which according to the direction of the division must remain with the other.

The ordinary form of asexual reproduction is, however, reproduction by **budding**. We then see a small bulging arise on some part of the body (*B*, Fig. 1), which, on closer examination, proves to consist of both layers of the body-wall, and to enclose a small diverticulum of the enteron. It gradually increases in length, and eight small tentacles grow out from its free end. Finally, a mouth-opening is formed between the tentacles and the young daughter-*Hydra* arisen in this way (to the right in Fig. 1) detaches itself from the mother-individual under concomitant closure of the posterior end of the enteron, which thus far communicated with that of the mother.

If the temperature is high and food abundant this multiplication goes on so intensely that not infrequently three or four buds in different stages of development may occur on one and the same specimen (Fig. 4), and that, occasionally, even a daughter-individual commences to produce buds of its own before its complete detachment. The whole process, as we see, rests on a multiplication of the body-cells, but does not in this case lead to a simple growth but to a production of new individuals. We here therefore have an example of the phenomenon pointed out on page 124, that growth in multicellular organisms may sometimes turn into asexual reproduction.

Whereas, in *Hydra*, the buds eventually always severe their connection with the mother-individuals this is no longer the case in certain of its relatives which, apart from internal characters, differ from it most conspicuously by the fact that, within their bodies, or round these, they secrete a calcareous substance which may considerably exceed the bulk of the animals proper. These forms also multiply by budding, but since the descendants do not separate they gradually transform into colonies, while the calcareous supports concomitantly grow out into a tree-shape. In this way, for instance, the red corals (مُرْجَان) arise: the substance we call by this name is the cleaned and polished skeletons of colonies of *Hydra*-like animals. Other species form tree-like masses with very numerous and thick branches of white colour, which, after the fashion of true trees, continually grow at the free ends of their boughs, while in the older parts the animals die. If such colonies rising in large numbers from the bottom of the sea reach the neighbourhood of the surface they represent the "coral-reefs" so well known, among others, in the Red Sea and elsewhere as a considerable hindrance to navigation; for the calcareous substance elaborated by the animals is as hard and often as solid as rock; many houses in the villages and towns along the Red-Sea-Coast being indeed built of this material.

The sexual reproduction of *Hydra* usually occurs only when incipient desiccation of the water, or sinking of the temperature, make conditions for the animals unfavourable. *Hydra* is a **hermaphrodite**, for both spermatozoa and egg-cells originate in the same individual, the former near the anterior, the latter near the posterior end. They develop from cells of the ectoderm, the surface of which becomes slightly bulged out at the respective places. In each testicular swelling (*Ts*, Fig. 1) numerous spermatozoa arise which after having reached maturity are evacuated into the surrounding water. Each ovarian swelling (*Ov*, Fig. 1) encloses only one mature egg-cell, capable of amoebic movement and containing, even then, specimens of the Alga *Chlorella* which have immigrated into it from the neighbouring tissues. The egg-cell is fertilised by a spermatozoon entering through the ectoderm, and then commences its cleavage which up to the blastula-stage is the same as above described. The transition into the gastrula-stage, on the other hand, takes place in a somewhat different manner, which will be discussed in connection with some further modifications of the gastrula-formation (Figs. 5–8 and p. 431). The egg which during these developmental processes has become surrounded with a resistant shell finally breaks forth from the ectoderm of the mother-individual and sinks to the bottom of the water. Here its content tides over the unfavourable period, escapes from the cyst when suitable conditions return, and grows out into a new *Hydra*.

The structure and biology of *Hydra* here briefly described include some points of general interest. Structurally, there is the peculiar form of the body which affords an example of the **radial architecture** explained on page 230. In fact, *Hydra* has neither a right or left side, nor a dorsal or ventral aspect; there is only the distinction between the anterior and posterior ends which determine the axis of the body. Around this axis, the tentacles are (apart from occasional deviations) evenly distributed, forming with one another angles of about 45°. Supposing we cut a *Hydra* up by sections passing all through the axis and in such a way that the whole body is divided into eight wedge-like portions with top angles of about 45°, these portions will all be structurally equal, and represent the "antimeres". The fact does not come out very markedly just in *Hydra* because of the excessive simplicity of this species. There are, however, related forms which, besides other complications, have longitudinal partition walls projecting for some distance into the enteron, while on, or between, the tentacles they develop sense-organs. All these parts are present in the same shape and arrangement in each antimere which thus possesses a part of every organ, and contributes an equal share to the building up of the entire body. Under these circumstances, the antimere appears to some degree as an individual which, originally independent, has associated itself with a number of its peers to form a body of a higher order. In *Hydra*, the number of such constituent parts is eight, that is, a multiple of four; in other Coelenterates the number is six, the antimeres then appearing in this number or multiples of it (12, 24, 36, etc.).

A point of interest in the biology of *Hydra* is its peculiar **mode of nutrition**. If we compare this with the same process as it goes on, for instance, in the human body (see p. 28) the difference which exists seems great, and yet it is only one of degree, not one of principle. In Man, as we have seen, the division of labour has led to a sharp separation of the various acts of which the whole process of nutrition is composed, and functional adaptation has brought about a corresponding dismemberment of the apparatus. In *Hydra*, division of labour has not yet been at work: the intestine is a simple sac anatomically, and the cells which line it all take about an equal share in both the production of the chemical reagents for liquefying the food and the absorption of the liquefied material. Nor do these simple conditions appear surprising in so small an animal which requires only a small amount of food, leaving a correspondingly small amount of indigestible remains.

A point of fundamental importance is intimately connected with the process of nutrition. After liquefaction, the ready-made food-material is, as we know, absorbed by the cells of the intestinal epithelium. In *Hydra*, these extend, together with the enteron, through the whole length of the body, including the tentacles, while the remaining parts of the body, viz. supporting membrane and ectodermal cells, lie everywhere closely against them (Fig. 2). There is thus for all these remaining parts, and in particular for the ectoderm-cells, no difficulty in obtaining from the entoderm-cells that share of the food which they require for their proper working. The fact, therefore, that the digesting and absorbing organ is throughout in intimate contact with all the other parts of the body dispenses *Hydra* from the necessity of developing any special contrivance for the distribution of the food, such as we saw was absolutely necessary in the case of Man (p. 33f). In *Hydra*, as a matter of **fact,** and in all the other Coelenterates, **the digestive cavity is at the same time the distributive cavity,** as indicated by the name "**Coelenterates**".

Regeneration.

Before leaving *Hydra*, I must shortly touch upon a phenomenon of general bearing, for the demonstration of which *Hydra* is in some sense the "classical subject". Nearly two hundred years ago, it was shown by experiment that, if a *Hydra* is cut in two, the halves do not die but within some time again transform into complete individuals; the anterior half producing a new posterior end, while the posterior half produces a new crown of tentacles with a mouth between them. The experiments succeed equally if specimens are halved longitudinally, or, if instead of being halved transversely, the body is cut into four, eight, and even more irregular portions; as a rule, all eventually yield small complete Hydrae, if they are only kept in healthy surroundings. The animals thus possess the faculty of "again producing" parts which have been lost, and hence the scientific term "**Regeneration**" for the phenomenon. It is, by the way, not altogether new to us; for you will remember, first, that *Hydra* even under natural conditions produces certain parts anew when by any spontaneous division these only remain with one of the daughter-individuals (p. 417) and, second, that exactly the same phenomena also occur in both the natural and artificial division of Protozoa (see pp. 93, 103 and 127).

A question of general biological interest is how these animals are capable of again producing parts that have been lost. According to our present views the capability has its reason in the as yet but slightly advanced specialisation of their bodies. This is most easily comprehensible in the Protozoa; as the cell of which each individual consists is able to reproduce the respective parts in the natural course of events, so it may also be credited with the ability to produce them anew if they have been lost by accident. *Hydra* on the other hand, consists of many cells and, what is more, of cells specialised into entodermal and ectodermal cells. However, we had already to point out that this specialisation is as yet little advanced; indeed it does not prevent both forms of cells, even in full-grown specimens, from multiplying and building up entire young individuals in the process of budding above described. For the formation of these buds ultimately rests on a multiplication of the cells at the place of origin of the bud, as shown with sufficient clearness by the fact that the body-layers of any daughter-individual are up to its separation mere continuations of the corresponding layers of the mother-individual (Fig. 1). Thus, if the body-cells of *Hydra* are capable of producing, by simple multiplication, entire new individuals, their capability of merely reproducing lost portions of the old body is in no way surprising.

A similarly extensive power of regeneration, after artificially received injuries, as that possessed by *Hydra*, is observable in many lower animals, and also coexists in these with natural regeneration in the course of asexual reproduction by division and budding. An interesting special example will still have to be mentioned in connection with the description of the earthworm (see p. 473). However, as the capability of asexual reproduction disappears in the higher animals, so the power of regeneration also diminishes in the measure as the division of labour and functional adaptation bring about a greater specialisation or, what is the same, a higher organisation of the animal body.

To mention a few steps in this gradual decrease, regeneration is still existing, but considerably reduced, in the **Arthropoda** and certain **lower Vertebrates**. If we cut a spider, or a crab, in two, the halves will invariably die ; but when one of these animals loses a limb, or part of a limb, this can in many cases be formed afresh. You probably remember the large crabs which are offered in the streets of this town for consumption (أبو جلمبو) ; if you compare a number of them attentively you will notice that, occasionally, the scissor-like terminal joints of their fore-feet are of more or less unequal size, or that one, if not entirely missing, is represented only by a short stump. These abnormalities have their reason in the fact that the original joints were lost by the crabs and are now being regenerated ; the various sizes indicating various stages in the advancement of the process. In old houses and dark cellars of this country a fairly large grey spider (أبو بيض) is often met with ; if, while trying to take it up with a forceps, you only grasp it by some legs, these will at once come off, while the spider escapes with the rest; but the loss does not concern it much because it will be repaired by the missing limbs growing afresh after a short time. Further, you perhaps know those lizards (scientifically termed *Ascalabotes*, Arabic برص) frequently found in this country, which by their particularly broadened feet are enabled to climb up smooth walls and even window-panes. Their tails, which in the normal condition evenly taper from root to tip, are often seen to present irregularities in length and diameter. The reason is that they break off invariably when Man or some other enemy happens to seize their owners by the tails, but that the lost portions are after some time regenerated; the broken surface, at first flat, becoming gradually raised into a short conical stump which grows until the original size of the organ is again reached. In the case of these lizards as well as in that of the spiders and crabs above mentioned the capability of regeneration is thus no longer general but limited to certain exposed parts of the body which are particularly likely to be lost.

A close examination even shows that, e.g. in the crabs and spiders, the respective parts break off fairly regularly at a place which is marked by a noticeable thinness of its covering, and that, consequently, the animals are in some sense prepared for giving up the parts in question. The whole is thus evidently a safety-measure; for if attacked or caught by some enemy they may escape with the loss of a small part of their body, capable of being reproduced later, while otherwise they would fall victims to their aggressor altogether.

The various constituent tissues of the regenerated parts are (with certain exceptions) supplied by the corresponding tissues laid bare by the fracture ; although specialised to a considerable degree, these still possess the faculty of reassuming an indifferent state and producing new cells of their special nature. One of the exceptions alluded to concerns the bone-tissue in the tail of the lizards; this is not capable of regenerating itself, and the consequence is that the regenerated tails do no longer have true vertebrae, but in their place only a simple cartilaginous rod.

In the **highest Vertebrates** (Birds and Mammals) the capability of reproducing lost parts is still further reduced, and mainly restricted to the **regeneration of tissues.** In Man, e.g. certain glands (thyroid, liver, also lymphatic glands) are known to reconstruct comparatively large portions if these have been removed ; in the case of the other tissues, however, the regenerative power is practically limited to the closing and healing of wounds. This result is in the main brought about by the cells in the immediate neighbourhood of the injury reassuming an embryonic state and by mitotic divisions producing new elements of their kind which by immigrating into the defect gradually restore the continuity of the tissue. Any larger losses of substance, however, cannot be mended and so operative surgery has recourse to the procedure of

"**Transplantation**" in all cases where such losses must be replaced for one reason or another. Leaving all details to your subsequent surgery-lessons I will here only state that transplantation, as indicated by the name, consists in taking a living piece of the respective tissue (either from the same or from another person) and fastening it to the required place ; if all goes well the piece heals in after the same method as ordinary wounds close.

From what we have said above about the relative facility with which regeneration takes place it may be inferred that similar transplantations will in lower animals succeed with much greater ease than they do in the higher. They are in fact frequently practised in modern experimental Biology for purely scientific purposes and have yielded a number of very interesting results, which, however, cannot be discussed here.

In conclusion, it may only be mentioned that the well-known procedure of "**Grafting**" in plants is biologically nothing but a transplantation; the most suggestive fact being that the various modifications in which the process is carried out in practice all agree in the one point that the new pieces are implanted into the old in such a way as to bring their respective embryonic tissues, i.e. the cambium-layers into close mutual contact.

Concerning the part played by the cambium in regeneration, as it occurs among the higher plants, compare page 355.

2.—ON SOME MODIFICATIONS IN THE CLEAVAGE AND GASTRULA-FORMATION.

A.—Modifications in the Cleavage and Blastula-Formation

(Plate XX.)

When discussing the division of the cytoplasm in a general way (p. 119f) I alluded to differences occurring in the cleavage of the eggs, and when speaking of these (p. 174), I mentioned that they vary a good deal owing to the amount and the distribution of the yolk deposited in them. Both differences are connected with one another in so far as the latter are the cause of the former.

The fact that the alecithal eggs contain no yolk, or only so little that its presence does not practically disturb the equilibrium of the cell, is the reason why we consider the cleavage of these eggs (as described on p. 410) as the normal and original type. The process, as already hinted, is still very similar in the eggs, both centrolecithal and telolecithal, which have a limited amount of yolk; the chief difference being that the presence of the heavy yolk sooner or later leads to an

Unequal Cleavage (p. 119). In some animals (as e.g. Nematodes) the very first division is unequal, as it takes place at right angles to the axis of the later embryo and separates an anterior cell with lesser yolk from a posterior which, as it contains the greater part of the original yolk, is both larger and less transparent than the former. We shall see presently that the anterior cell, or its descendants, generally supply the external covering and the "animal organs" of the body, that is, the nervous system and the sense-organs distinctive of the animals, while the posterior cell gives rise to the "vegetative organs", i.e. those concerned in the "household-work" of the organism and occurring in an equivalent form also in the plants (see p. 31). These differences have led to the distinction of the first two cleavage-cells of the Nematodes (and the corresponding cleavage-cells of other animals) as the "animal cell" and the "vegetative cell" respectively; hence, furthermore, the designation "animal pole" (p. 177) for that pole of the undivided egg-cell at which the animal cell (or animal cells) will form later, and the designation "vegetative pole" for the opposite pole occupied by the vegetative cell (or cells).

In other animals (as e.g. the frog and its relatives) the two first divisions of the egg-cell are longitudinal

(Figs. 1 and 2) and only the third is transverse; here, consequently, the inequality, i.e. the distinction between animal and vegetative cells does not make its appearance until the third division (Fig. 3), but becomes emphasised while the cleavage goes on, owing to the vegetative cells, burdened as they are with the yolk, dividing much more slowly and hence remaining larger and less numerous than the animal (Fig. 4). In the end, a blastula arises which differs from the one we thus far know (Fig. 5, Pl. XX) by generally thicker walls and a blastocoel which is markedly shifted towards the animal pole by a thick cluster of vegetative cells projecting inwards (Fig. 1, Pl. XXII).

Although the inequality here described in the size of the animal and vegetative cells is to a large extent undoubtedly due to the presence of the yolk, it yet becomes frequently apparent even in eggs with little or no yolk. Thus Figures 1–4, Plate XX, though actually referring to the telolecithal eggs of the frog, may as well serve to illustrate the segmentation of an alecithal egg yielding a blastula such as Figure 5, in which animal cells *A* and vegetative cells *V* are distinguishable by their slightly but clearly different size. Similar conditions are shown by the blastula Figure 5, Plate XXI.

Equal and unequal division are varieties of what we formerly called the **total division** of the cell; the eggs which show this mode of division are in Embryology also combined under the term "**Holoblastic**[*] **Eggs**". The decisive influence exerted upon the details of the cleavage by the yolk is clearly recognisable in them, but becomes much more apparent in the eggs which, for some time at any rate, only **cleave partially** and hence are distinguished from the holoblastic as "**Meroblastic*** **Eggs**". They are those which possess a very large amount of yolk, the special localisation of which again entails certain modifications of the cleavage-process.

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[*] Greek; from ὅλως—entirely, altogether; and βλαστάνω—to germinate (see also βλαστός—note.*, p. 410).

In the **strongly telolecithal** eggs there is a "**Discoidal Cleavage**"†. In the birds e.g. we saw on page 176 that the nucleus, surrounded only by a small area of protoplasm free from yolk-granules, lies quite at the upper surface of the egg-cell, in the germinal disc (*N* in Fig. 4, Pl. X). If, in this position, it divides, it seems comprehensible that its dividing power is not sufficient for breaking up the whole mass of the underlying yolk into two portions; in fact, after the division of the nucleus, there arises between the daughter-nuclei only a cleft which separates the germinal disc, i.e. only a superficial layer of the egg-protoplasm, into two areas but leaves all the rest of it undivided. A fresh division of the daughter-nuclei leads to the formation of a second cleft at right angles to the first, which divides the surface of the germinal disc into four areas, but otherwise does not alter the previous conditions. When seen from without the disc at this stage presents the aspect shown in Figure 8, Plate XX, while a cross-section (somewhat later) would reveal conditions such as depicted diagrammatically in Figure 9, the areas marked off by the clefts and containing each a nucleus fusing completely with one another deeper down. In the same way more divisions follow, and not until the surface of the germinal disc has become broken up into a fairly large number of small areas (Fig. 10) does the first complete isolation of cleavage-cells take place. It is clear that only a division the plane of which runs parallel to the surface of the egg-cell can have this effect; and it is equally clear that, while such a division completely separates a layer of superficially situated cells there remains, below these, another layer the members of which still hang together with the undivided yolk as before. These conditions are diagrammatically shown in cross-section in Figure 11. Other divisions of the same sort follow the first, and so I think you will see that the end of this partial division must be the transformation of the original germinal disc into a superficial mass of completely isolated small cleavage-cells, below which there always remains a layer of others which by their basal portions are still continuous with the yolk. Between this latter layer and the superficial cells, there gradually arises a cavity which converts the whole into a blastula, differing from the typical form chiefly in the fact that the vegetative cells are here represented by the undivided yolk of the egg-cell together with the nuclei contained in it. The fact that the whole cleavage-process remains here restricted to the germinal disc has led to the above designation " discoidal cleavage ".

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* From μέρος—see note *, p. 133, and βλαστάνω.— see preceding note.

† From the Greek δίσκος—disc.

Another variety, differentiated as "**Superficial Cleavage**" is found in the **strongly centrolecithal** eggs of the Arthropoda. The process is in the main a "multiple division" as described on page 113. The original nucleus of the egg-cell, by repeated divisions, breaks up into a large number of daughter-nuclei, grand-daughter-nuclei, and so on, which for some time remain in the yolk (Fig. 12, Pl. XX), then nearly all come to the surface almost simultaneously, in order to transform into small cells. This they do after the same fashion as we previously found in *Gregarina* (p. 135); in the egg, of course, they do not detach themselves, either from one another or from the yolk, but form a continuous layer all round the latter, while some of the nuclei, as already hinted, remain within it (Fig. 13). In the majority of the Arthropod-eggs no cavity is formed which corresponds to the blastocoel; nevertheless, other facts upon which I cannot here enter, leave no doubt that the stage just described is a particularly modified blastula-stage.

B.—Modifications in the Gastrula-Formation.

While the transformation of the egg-cell into the blastula is similar in all Metazoa, the above variations being mere immediate consequences of alterations in the amount and the localisation of the yolk, the formation of the gastrula is also subject to certain modifications, for which, however, there are no equally obvious reasons. One way of the gastrula-formation was described on page 411 and illustrated by Figures 5–7, Plate XX; as it consists chiefly in a bending inwards of half of the blastulà-wall we call it "**Gastrula-Formation by Invagination**"; it seems to be the original type, and is certainly the simplest type of the process. Of the remaining types known, I will here only mention the "**Gastrula-Formation by Polar Immigration**"; it is the mode by which (among others) the gastrula of *Hydra* arises (cf. p. 419). Here we see that, from a certain time onwards, descendants of the vegetative cells, instead of remaining within the blastoderm, emigrate from it into the blastocoel, there to form a cluster which, starting from the vegetative pole, gradually fills the whole, or nearly the whole, blastocoel (see Figs. 5–7, Pl. XXI). Somewhat later, a cavity arises in their midst (just begining to form in Fig. 8, Pl. XXI) around which the cells arrange themselves in a continuous (epithelial) layer, and eventually, the cavity breaks through at the vegetative pole, thus making the gastrula-shape complete.

The great majority of the modified blastulae above described transform into gastrulae after one of the two modifications here sketched. However, if conditions are somewhat complex even in the blastulae, they become doubly so in the gastrulae, and their description, in order to become comprehensible to you, would require more time and space than is actually at my disposal. So I will limit myself here to a few words about the simplest form of the process, as found in the **frog** and its relatives (see Pl. XXII). The gastrula is here formed by invagination. If you look at Figure 1, you see, marked o + in the optical section, a fairly sharp line of demarcation between the animal and the vegetative cells (*A* and *V* respectively) of the blastula. At some place of this line (let us suppose at the place marked + in the drawing) the invagination commences; it will be seen at once that this must become narrower and less regular than it is e.g. in Figure 6, Plate XX, because, above, there are only small animal cells, while, below, there is the whole mass of the large vegetative cells. So after some time the invagination takes the shape given in Figure 2 which I think will be understood. However, it is not yet the end of the processs, for the archenteron *AE* still pushes on deeper into the body and, while so doing, widens at its farther end (*AE*, Fig. 3). Concomitantly, the embryonic cells go on multiplying, and this leads to further important changes. The animal cells, originally, bordered upon the vegetative cells in the line marked o + in Figure 1. The point +, from which the invagination starts, thenceforward remains almost stationary (see + in Figs. 2 and 3), but along the whole rest of the line the more intense multiplication of the animal cells causes these to advance and push the vegetative cells inwards. Thus in Figure 2 they are seen to cover a rather more considerable portion of the embryo's surface (note the changed position of the point o), and in Figure 3, they have entirely invested the vegetative cells, with the sole exception of the small area between o and + through which these are still visible. With this stage, the gastrula of the frog (and its relatives) is complete; the whole outer surface is formed by the small animal—now ectoblast—cells (*Ec*); at the posterior end, there is a small blastopore (*BP*) which leads into the archenteron (*AE*) lined by the entoblast; this latter, formed of the original vegetative cells, is single-layered above and in the sides, but considerably thickened ventrally, as visible in the drawing; the blastocoel (*BC*), finally, has almost entirely disappeared.

3. — THE METAZOA-COELOMATA.

A.—The Body-Cavity or Coelom.

We must now once more turn to *Hydra*. It was emphasised on page 421 that its entoderm is everywhere in close proximity of the enteron (Fig. 2, Pl. XXI) and, consequently, can easily draw from this that share of the food it requires for its work. Let us now suppose that the tendency to perfection innate in the living substance acts in a *Hydra*, and causes it to assume a larger size, in concomitance with an increase in number of the cellular layers of the body, so that, in a cross-section such as Figure 2, we would find e.g. four layers instead of the really existing two. It is clear that under these circumstances only the layer next to the entoderm would be under the same favourable conditions as regards nutrition, as formerly was the ectoderm. These conditions become less satisfactory for the third layer, and are least satisfactory for the outermost layer which, under the new circumstances, naturally represents the ectoderm. For any food, in order to reach it, must pass through the two intermediate layers by which it may be withheld, in part or entirely. We thus see that any perfection in structure, accompanied by an increase in thickness, of the body-wall, is likely to entail a disturbance in the "nutritive equilibrium", as we might term it, of the different constituent parts of the body, and hence the necessity for the organism to ensure this equilibrium by suitable means. The means adopted for the purpose by all animals which have acquired a more advanced organisation is the formation of a cavity between the intestinal wall and the peripheral parts of the body, so that, on the one hand, the food elaborated in the intestine, by simply passing through its wall, can collect in the cavity, while, on the other, even the more distant organs can take from it what food they require. This cavity is, in a number of lesser advanced Metazoa, simply the blastoderm, or "primary body-cavity" (p. 410) in a more or less modified condition. In all more highly organised Metazoa, on the other hand, it represents a new formation known as "secondary body-cavity" or "**Coelom**" and may either replace the primary body-cavity or coexist, and even enter into communication, with it. The respective conditions vary to some extent in the different Metazoa and are, in addition, frequently not easy to ascertain. In general, however, we differentiate all Metazoa which possess a (primary or secondary) body-cavity as "**Coelomata**" from the Coelenterata, which have no similar cavity (see also p. 229).

The coelom is thus an organ of vital importance for all the more highly organised Metazoa, and in accordance with this fact is formed very early in their embryonic development. It is perhaps best to at once say some words about this development, as it is not only intimately connected with the later formative processes in the metazoan body, but may also serve to explain structural details we find in the coelom of the more advanced Coelomates.

B.—The Mesoblast and the Formation of the Coelom. The Germinal Layers.

If the above theoretical considerations are correct the coelom would owe its origin to the interposition of new cellular layers between ectoblast and entoblast. This interpretation is borne out by the way in which the coelom is practically formed in the embryo. Before going further, I must mention that this way is not the same in all Coelomates; also that the variations alluded to on page 432 may modify it considerably. All these deviations must here be left out of account; I must limit myself to the description of one process of coelom-formation which may be regarded as typical, and will suffice to show you the significance of both the coelom itself and the new cellular layers which make its formation necessary.

For this purpose let us return to the gastrula of the frog (and its relatives), as we left it on page 433. A cross-section made through this stage at right angles to the plane of the paper, and at about the place indicated by the arrow in Figure 3, Plate XXII, would give a picture as represented in Figure 4. There is, all round the embryo, the layer of small ectoblast-cells (*Ec*), while inside we have the cavity of the archenteron (*AE*) lined by the entoblast-cells (*En*) which, above and laterally, form a single layer, but below are crowded into a thick cluster; the narrow clefts at places visible between ectoblast and entoblast are remainders of the original blastocoel. The cellular layers between which the coelom subsequently arises are supplied from the entoblast. We see in Figure 5 that the archenteron-wall, on each side and near the dorsal median line, forms a thickening (*Me*) which, projecting outwards, pushes itself in between the two primary germinal layers (see p. 413). It gradually increases in size (right half of Fig. 5), until it meets its fellow of the other side in the ventral median line and there fuses with it.

By this process (which is in truth somewhat more complicated than was here described), the embryo which hitherto consisted of two layers has been converted into a three-layered body; and since the new layer, as we shall see presently, is embryologically as important as ectoblast and entoblast, we consider it as a **third germinal layer** and call it "**Mesoblast**"*. It is, at first, apparently solid; in later stages, however, a fine slit, starting, as indicated by the arrows in Figures 5 and 6, from the enteric cavity, and therefore representing a continuation of this, pushes on into it, and in the end separates the entire mass of the mesoblast into two lamellae (*Me* in Figs. 6 and 7), one of which thenceonward remains in close proximity to the wall of the archenteron, while the other seeks equally intimate contact with the ectoblast. The slit between them (*Coe*, Figs. 6 and 7), previously continuous with the archenteron, subsequently severs its connection with this by a closure of the communications at the points of the arrows in Figure 6, and thereby becomes an independent cavity (*Coe*, Fig. 7) which is the **Coelom in its earliest shape**. The two layers into which it divides the originally solid mesoblast are termed the "**Splanchnic**"† and "**Somatic**"‡ **Mesoblast** respectively, and a cross-section through the embryo then exhibits conditions as represented in the diagram (Fig. 8). Ectoblast (*Ec*) and entoblast (*En*), this latter lining the archenteron (*AE*), are as before; between them, there lies the rather voluminous mesoblast, divided into the somatic part (*SoM*) and the splanchnic part (*SpM*). Both are separated by the wide coelom (*Cœ*) which is only interrupted in the dorsal median line by a thin lamella of mesoblastic tissue representing the later mesentery. So we see indeed that the formation of the coelom is causally connected with an increase in number of the cellular layers which compose the body.

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* From the Greek μέσος—middle, intermediate.

† From the Greek τὰ σπλάγχνα—the viscera.

‡ From σῶμα—body, trunk.

It seems conceivable that the organism, while it becomes complicated in this way, also requires structures to keep the various parts in place and to strengthen the body as a whole. For it results from the preceding description that all the systems so far present have merely the shape of **epithelia**, that is, of layers composed of cells which adhere sufficiently to one another within a layer, but have little or no cohesion with the other layers. In a word, the organism requires "connective" elements. Such elements are in fact present even in many Coelenterates. You remember the thin gelatinous "supporting membrane" of *Hydra*; in other Coelenterates it is considerably thickened and, as in this state it would require stabilisation, is crossed in all directions by the processes of irregularly star-like cells which are embedded in the membrane and represent connective elements. In the embryos of the respective Coelenterates, these cells originate singly from the vegetative pole of the blastula, and thus never form a coherent layer between ectoblast and entoblast, as does the true mesoblast in the same situation. In the body of the Coelomates similar cells attain a much greater importance and become much more numerous; but, nevertheless, retain their characteristic peculiarity of originating, not in the shape of continuous epithelia, but singly. They are, in the embryos, differentiated from the entoblast almost simultaneously with the mesoblast, and subsequently invade all the spaces between this and the other organs; but as they have quite a different mode of origin we distinguish them and their descendants from the true mesoblast as "**Mesenchym**"* (*Mch* in Fig. 3, Pl. XXII).

I have just said that the mesenchym-elements invade "spaces" between the other organs. Such spaces exist indeed and are probably remnants of the blastocoel or "primary" body-cavity (see e.g. *BC* in Fig. 3, Pl. XXII); this, therefore, does not entirely disappear, despite the formation of the "secondary" body-cavity, i.e. the true coelom. The spaces mentioned seem to maintain themselves even during later life, representing wider or narrower clefts between the tissues, or even between the cells of certain tissues. But they are different from the true coelom, although they exist beside it and may, in various Coelomata, even coalesce with it by a secondary disintegration of the coelom-walls. Here we have some of the deviations to which allusion was made on page 434; they cannot, however, be discussed further.

By the differentiation of mesoblast and mesenchym the entoblast has somewhat changed in nature; for, while, originally, it included the germs of these structures, it has now been divested of them and thus represents, we might say, a "purer" entoblast than before. For the sake of precision, we distinguish it in scientific language as "**Secondary Entoblast**" from the earlier "**Primary Entoblast**".

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* From μέσος—see note *, p. 436, and ἔγχυμα—something poured into a receptacle (see note *, p. 340).

During the processes here briefly outlined the primordia of some other important systems of the frog's body have also made their appearance. As the respective details could not be omitted in the drawings unless these were to become quite unnatural, I must here explain them so far as they go, whereas the rest of the subject must be left to your Embryology-lectures. The systems alluded to are the nervous system and the notochord.

The nervous system originates from the ectoblast. Even before the mesoblast becomes first visible the embryo which at this time begins slightly to stretch appears somewhat flattened along the median line of its dorsal surface (Figs. 4 and 5, Pl. XXII), while the ectoblast-cells, within this flattened area (the so-called "medullary plate"), assume a prismatical shape, (*MP*, Fig. 6). Later, the normal ectoblast-cells grow over the flattened area, forming first, on each side of this, a small longitudinal ridge (marked ++ in Fig. 7), and thus converting the medullary plate into the "medullary groove". Both ridges gradually broaden towards the median line, in which they finally meet and coalesce with one another. The original area of prismatical cells is thus separated from the ectoblast (of which it previously formed an integral part) and displaced below it; by a subsequent bending upwards of its margins it is transformed into the canal which represents the primitive form of the later cerebro-spinal nervous system (*Nrv* in Fig. 8).

The notochord, or chorda dorsalis, originates from the entoblast, and in particular from that part of its dorsal circumference which lies between the points of departure of the two mesoblast-folds between the points of the arrows in Figure 5. This part, at first flat (Fig. 5), by a gradual rising of its median portion, assumes the shape of an inverted groove (*Nch*, Fig. 6), and eventually that of a solid rod (*Nch*, Fig. 7), below which the enteric wall of the one side joins that of the other and fuses with it. After the mesoblast-primordia have severed their connection with the original entoblast the same is done by the notochord-rod, and we then have the conditions as diagrammatically shown in Figure 7. Here the wall of the archenteron is again closed in the dorsal median line, while, above it, there lie, in the middle, the completely isolated notochord (*Nch*) and, on either side, the mesoblast-folds (*Me*) also completely isolated and with the coelom (*Cœ*) beginning to show more clearly within them. The cerebro-spinal canal is not yet closed, but still exhibits the shape of the medullary groove bordered by the just arising longitudinal ridges. For further details of these developmental processes, I have already said that I must refer you to your Embryology-lectures.

I conclude the discussion by a short recapitulation of the chief features of general biological interest which may be found in the early development of the Metazoa. The primitive form of the body is that of a bladder with a wall made up of a single layer of cells. A commencing division of labour leads to an arrangement of these cells in two layers; the cells which devote themselves to the "household-work" of the organism withdrawing inwards, while the others which control the mutual relations between the organism and its surrounding keep their superficial position. A new step forward in the division of labour results in a further "splitting up" of the two primitive systems. This is not very intense in the outer layer, and consists merely in a separation of a central nervous system from the rest of the layer; in other words, in a specialisation between the nervous and the protective functions of the original ectoblast. The "splitting up" is much more intense in the inner layer, obviously in connection with the fact that the "household-work" can, and in fact does, vary much more in the various organisms and is thus capable of much greater specialisation. So we see that the "primary" entoblast not only becomes divided into two separate germinal layers, viz. the mesoblast and the "secondary" entoblast, but, besides, also sends out the mesenchym-germs into the interspaces between the new formations. In the general biological sense, these differentiations mean a separation from one another of the digestive, the distributive, and the connective functions of the primary entoblast.

You thus see I think how the principle of division of labour, now here, now there, brings about a breaking up of systems which previously had a more generalised function, and how the principle of functional adaptation concomitantly brings about an arrangement of the new parts which is in evident accordance with the more specialised work they have to perform in the service of the whole. What has in this way been started in the early development is persistently carried on later, although secondary modifications may occur in the different types of the animal kingdom. The systems, at first of the simple shape of tubes or folds, begin to form dilations, or outgrowths, or new folds, which represent the primordia of the later organs. When these have become unfolded the differentiation of the tissues sets in, that is, the cells which up to this time in the main multiplied, and for the purpose had to preserve an indifferent shape (note the uniform and fairly regular shape of all the cells in the developmental stages figured, and compare further p. 44) assume the outer form and internal structure determined by their now fully specialised work. During these processes, it often becomes necessary for the derivates of one germinal layer to push in between those of another, and quite especially is this the case for the derivates of the mesenchym, the particular function of which is connecting. In conclusion of this general picture, let me here shortly state how the derivates of ectoblast, mesoblast, secondary entoblast and mesenchym participate in the building up of the definitive Coelomate-body.

The ectoblast supplies, on the one hand, the nervous system and the nervous portions of all the sense organs ; on the other, the skin and any protective secretory or respiratory structures it may develop. The mesoblast supplies the epithelial lining of the coelom, the sexual cells and the chief parts of the musculature, in such a way that the muscles of the body-wall originate from the somatic, those of the intestinal wall from the splanchnic mesoblast. The secondary entoblast supplies the epithelial lining of the alimentary canal and the secreting parts of all the glands which may adhere to it. The mesenchym, finally, supplies the connecting elements ; not only those which are literally connective and supportive, but also others which, when present, are "connecting" in a somewhat wider sense, namely, the blood and the circulatory apparatus.

We herewith conclude the chapter on the embryonic development of the Metazoa. The facts which have been selected for discussion will I hope suffice to give you an idea of the ways, different in detail, but similar in principle, by which a single cell is able to yield a body specialised into systems, organs, and tissues. It would now be our task to study in some detail the anatomical structure of a few further advanced types of Coelomata in their adult condition. Unfortunately, the respective forms do not occur at all, or are only represented by small congeners, in Egypt. In accordance with the tendency of these lectures to dwell, within the limits given, on facts of general interest and bearing rather than on details and deviations, I prefer to in a certain sense continue the preceding discussion, i.e. to relate, in a succinct form, how the primitive organs, probably possessed by the early Metazoa and still demonstrable at present in their embryos, become unfolded further, and how the definitive shape they assume is, in any given case, controlled, by their function on the one hand, and by the relative degree of perfection of their owners on the other. For simplicity's sake, only the animals described in the preceding pages and, to some extent, those above mentioned which we ought to have studied additionally will be referred to. The description will, furthermore, be limited to the vegetative organs; an inclusion of the animal organs would widen the field considerably, but seems dispensable on account of what you learn about these organs and their function in Anatomy and Physiology.

C.—Further Differentiations of the Coelom.

The Circulatory System.

Let us return to the body-cavity. It represents, in its simplest form (Fig. 8, Pl. XXII), a cavity closed all round and interposed between the intestinal wall and the body-wall; its function is to establish an interchange of nutritive material between the intestine in which the food is prepared and the peripheral organs in which it is consumed. This consumption, as we have seen on an earlier occasion, is inseparably connected with the formation of waste-products which must be eliminated from the body. As the peripheral organs take their food from the body-cavity, it would seem natural, a priori, that they should also evacuate their waste-products into this. Reserving the latter point for a separate discussion we direct our attention for the present solely to the process of nutrition.

If the nutritive fluid, or "chyle", reaches the body-cavity by passing through the intestinal wall, it will chiefly accumulate in the immediate neighbourhood of the latter; in order to bring about a distribution, it is necessary that the fluid should be moved. If you place a piece of sugar in a glass of water and then leave the whole alone, the sugar will dissolve, but at first only form a very concentrated solution at the bottom of the glass. It will take a long time for it to become equally mixed with the water; but you can bring about the same result within a few seconds by stirring the water. In a similar manner, motion would seem advantageous in the interest of a speedy distribution of the nutritive substances throughout the body-cavity. But this is not all; for the motion must, in the living organism, even be kept up constantly or, at any rate, at short intervals, because any equal distribution established at a certain moment is, in the next, again abolished by the fact that the food-substances are consumed peripherally and produced centrally.

This motion of the coelomatic fluid or the "blood", as we may call it in a somewhat amplified sense, is in the lower Coelomates simply brought about by the movements of the body proper. If you look at the Nematodes represented in the Figures of Plate XII you see everywhere between the body-wall and the inner organs an empty space which is the body-cavity, and is in reality filled with a limpid fluid containing some amoeboid cells derived from the mesenchym. These animals are, while alive and under suitable conditions, in almost constant motion which in the first place may serve for locomotion, but secondarily also serves the purposes of metabolism. However, if we reflect a little further, we will see that a device like that under consideration can only suffice in the case of a comparatively small and simply built body, and can suffice, furthermore, only in cases where no hard parts interfere with its contractility as a whole. In explanation of this latter point I recall e.g. the snails living in a hard, actually immobile house, or the Insects (see p. 233) invested all round in an external chitinous skeleton, or, finally, the Vertebrates which, owing to the presence of their internal bony skeleton, cannot contract in the same way as for instance a *Hydra* can. While, therefore, in the lower Coelomata, the movements made for the purpose of mere locomotion simultaneously bring about a stirring of the blood-fluid which meets the requirements of the organism, this is no longer the case in the higher Coelomata. These animals, then, must have recourse to another expedient for keeping their nutritive fluid in motion, and this expedient is the **circulatory system**.

We have already spoken of its general structure and function in an earlier chapter (pp. 33 ff). Let us now investigate a few of the phases through which it has presumably passed while acquiring the highly perfected arrangement it actually presents in the advanced Vertebrates.

In about its simplest form we find the circulatory system in certain **Arthropoda** (chiefly **Insects**). These have only a "heart" (Fig. 1. Pl. XXIII) that is, a small sac or tube situated in the body-cavity under the dorsal surface (compare here p. 235) and supplied with a number of lateral valves (*Va*), while the anterior and posterior ends are open. This sac or tube, just as the heart of Man, makes constant rhythmic contractions, the fluid being sucked in at the lateral valves, and forced out again at the anterior opening (as indicated by the arrows in the figure quoted). Simple as such an organ may be, it serves its first and foremost purpose, namely, that of keeping the "blood" in motion, while the distribution of the latter to the different parts of the body is still more or less left to chance. But this is just the point where perfection sets in. We see the openings of the heart, especially the anterior opening, run out into tubes (slightly developed even in the heart depicted in Fig. 1, Pl. XXIII) which conduct the blood for some distance towards the more important organs, but eventually again open into the body-cavity. A whole system of fairly long and ramifying tubes may arise in this way (e.g. in crabs), but the remarkable fact is that, so far, all these "vessels" only correspond to the arteries of the higher Metazoa, i.e. serve for the distribution of the nutritive substances, whereas the returning blood still has to find its way through the body-cavity.

Originally, this latter movement is quite irregular, only that the blood must return to the heart sooner or later, owing, on the one hand, to the pressure which the fluid constantly emerging from the openings of the arteries exerts upon it from behind, and, on the other, to the equally constant sucking action of the heart. It seems clear that under these conditions there can be but little regularity in the backward blood-current, and it may therefore be anticipated that another step in the gradual perfection of the circulatory system will be the formation of veins, i.e. of vessels which regulate the backward movement of the blood in a similar manner as the arteries regulate its outward movement. The conditions are sometimes (e.g. in certain larger crabs) foreshadowed insofar as there are no proper veins yet, but in their place particular sinuses and channel-like spaces of the body-cavity which receive the blood and convey it to the heart.

A circulatory system composed of arteries and veins is, among others, found in the **snails** (جرج). It seems, in this state, comparatively highly developed, and yet still retains the primitive character of being "**open**"; which means that the ends of the arteries are not continued into the commencements of the veins, but that, between the two, parts of the coeloma, or, at least, of the inter-tissue-spaces above mentioned (p. 438), are still intercalated.

A "**closed**" **circulatory system**, i.e. one in which there is a direct passage from the arteries to the veins, is only rarely found among the Invertebrates (an example is the earthworm), but is characteristic of the **Vertebrates**.

Even in these, however, there is no absolute isolation of the blood-vessels from the other cavities of the body, for the inter-tissue-spaces, while fusing to form a set of distinct vessels known as lymph-vessels, still communicate with the blood-system by the thoracic duct. The details you will be taught in Anatomy and Physiology.

(a) The Relations between the Coelom and the Respiratory Organs.

While the circulatory system becomes in this way ever more individualised from the general body-cavity it seeks connection with certain other systems. Thus we have seen previously that the circulation plays an important part in the process of respiration (p. 34). The anatomical association between the respective systems begins in fact to manifest itself with the moment at which special organs for respiration appear in the metazoan body; it may become so intimate that many particulars in the structure of one system are only fully comprehensible if confronted with the structure and function of the other. Before we go further it is therefore necessary to cast a short glance on

The respiratory organs of the Metazoa. We know that there are none yet in *Hydra*; the peculiarity is shared by quite a number of the smaller Coelomates, among which is the earthworm. Its respiration is effected by the general surface of the body which absorbs the oxygen from the surrounding medium, while the blood circulating beneath the skin in the superficially situated parts of the coelom (or corresponding parts of the primary body-cavity) is enabled to take it up and convey it to the rest of the body. If the instance of the earthworm shows that the skin can respire it is not surprising to see that, in many Metazoa with special organs for the purpose, these represent outgrowths, i.e. enlargements of the surface, of the skin. As one example out of the many that exist I will again quote those crabs which are sold by street-pedlars (*Portunus pelagicus*, أبو جلمبو أو فاجوريا); if you carefully exarticulate their legs you will discover, adhering to the basal portion of each, feather-like structures which are the respiratory organs of the crabs. Quite similar organs are found, on either side and shortly behind the head, in the tadpoles of the frog (see p. 217); only that, here, they are hidden from view by a membrane which covers them from without (in certain near relatives of the frog which, however, do not occur in Egypt, the membrane is absent and the respective organs can therefore freely be seen).

We generally term respiratory organs which appear as external, feather- or leaf-like appendages of the skin "**Gills**"; but a simple reflection shows that they are only possible in animals living in water, or at least, in very moist surroundings. For since the gills are destined to absorb oxygen they must have a thin and permeable surface; a character which, in its turn, will favour evaporation and might, in the air, easily favour it to such a degree that a drying up of the gills and concomitant suffocation of their owners results. This must be prevented, and so we see that a respiration by gills is naturally connected with a life in water, from which the oxygen is absorbed directly, as described on page 6.

In the animals which absorb the gaseous oxygen of the air, on the contrary, the respiratory organs are for the same reason displaced into the body, where they are safely protected from desiccation, but apart from this resemblance, show a fairly different arrangement in the different types of the Coelomates. When speaking e.g. of the mosquito-larvae (p. 212) we mentioned "breathing tubes"; indeed, if we examine such a larva (or any other insect) more closely we will notice a large number of fine tubes which communicate with the exterior by two or more openings (the so-called "**Stigmata**"), while inside the body they break up into a rich system of ever finer ramifications which make their way all over the surfaces of the different organs. These tubes appear white under reflected light (i.e. when seen with the naked eye or under a pocket-lens) and blackish under transmitted light (i.e. when observed under the microscope), a feature which is the consequence of their being filled with air. In fact, these tubes are the respiratory organs of the Insects, known under the special name "**Tracheae**". In the case of the mosquitoes they have been retained by the larval stages although these have secondarily adopted a life in water (see p. 220f).

In the Vertebrates, the respiratory organs appear in the shape of "**Lungs**". These are in principle two hollow bags which originate as an outgrowth, at first simple, but later bifurcating at its end, of the initial part of the intestine, with which it also remains connected throughout life by the larynx and (if this exists) the trachea. Apart from this common character, the general appearance of the lungs varies considerably in the different Vertebrates. If we examine, for instance, the lungs of a frog, they still show each the shape of a bag, i.e. a large cavity surrounded by a wall; but this wall is somewhat thickened and exhibits a particularly spongy texture which on account of the numerous blood vessels pervading the framework obviously serves to increase the respiring surface of the organ. If, on the other hand, we examine the lung of a mammal, we no longer find any similar distinction between a cavity and a wall; the whole lung, apart from the ramifications of the trachea, represents an apparently uniform spongy mass permeated with innumerable fine air-spaces and, between these, as innumerable fine blood-vessels. In the biological sense this difference means an enormous increase in the size of the respiring surface (compare here p. 317).

Now let us return to the connection into which the circulatory system enters with the respiratory system. We said above that this connection becomes apparent as soon as special organs for respiration are differentiated in the metazoan body. This is, among others, very instructively illustrated by the **Insects**. I may mention here that these are about the most highly gifted representatives of the Invertebrates, a statement in proof of which I will only quote the well-known habits and capacities of the bees, the ants, and others. And yet these Insects, as we saw on page 445, have only a very primitive circulatory system (Fig. 1, Pl. XXIII). It is in this case the tracheae which make up for the deficiency, for, spreading as they do all over the organs of the body, they convey the oxygen of the air to these and the blood in general. We scientifically describe the conditions by saying that the "**respiratory organs seek the blood**". That these conditions are indeed sufficient for bringing about an intense respiration is proved by the fact that the bee, e.g. is one of the few invertebrate animals in which a temperature higher than that of the surrounding has been demonstrated (p. 191), and is further proved by the fact that many Insects show external signs of their respiration (see p. 6). For if you observe e.g. a bee you will notice, especially in warm weather, that its abdomen is making constant rhythmic movements of contraction and extension, movements by which air is alternately pressed out from, and sucked in into, the tracheae.

While in the Insects the respiratory organs seek the blood, the reverse is the case in the great majority of the other Coelomates; for in these "**the blood seeks the respiratory organs**". Among the arteries of the crabs e.g. there are one or several on each side which open at the base of the gills and thus cause a certain amount of the blood to constantly go to these, for the sole purpose of respiration. The decisive influence exercised upon the arrangement of the circulatory apparatus by the particular development and situation of the respiratory organs is, however, most conspicuously brought into evidence among the **Vertebrates**. The short review which I am now going to give of the conditions observable in these will reveal the further fact that the anatomical complexity and physiolgical efficiency of both organs increase commensurately with, and are indeed the gauge of, the perfection of the organism as a whole.

You probably know that the **fishes** living in water and respiring by gills stand lowest in the Vertebrate series. Their heart (compare Fig. 2, Pl. XXIII) is "simple", i.e. consists of one "chamber" (or ventricle; *Vt*, Fig. quoted) and one "ante-chamber" (the auricle, or atrium; *At*, same Figure) and lies shortly behind the head in the ventral part of the body-cavity. Its active portion is the ventricle; by its contraction, it sends the blood to the gills by means of a median stem, the "ascending aorta", which, as it runs forward, divides into (usually) eight "aortic arches" of which four lie symmetrically on either side. Each arch enters a gill as the so-called "afferent branch of the arch" (*Aff* in the Figure) and there breaks up into "capillaries", i.e. a large number of very fine vessels ([*Gi*] in Fig. 2) in which the blood has abundant opportunity to absorb oxygen from the water bathing the gills; some details of the arrangement are given in Figure 3, which represents a cross-section through the gills. The capillaries then collect again into larger, so-called efferent, vessels (*Eff* in Fig. 2) which appear as continuations of the original aortic arches and finally all eight fuse to form the large "descending aorta" situated in the median line under the dorsal wall of the body-cavity; it is shown but not marked by letters, in Figure 2. It runs backward, and by its ramifications distributes the blood to the peripheral organs in which the oxygen is given up and exchanged for carbonic acid. By means of the veins the blood then returns to the heart, entering it through the auricle and being by the ventricle sent on its course to the gills anew, as shown by the different arrows in Figure 2, Plate XXIII. We thus see that in the fishes the respiratory organs are intercalated in the general circulation; the blood makes only one circuit through the body, and that which passes through the heart is of only one kind, namely, "veinous" blood rich in carbonic acid. Another characteristic feature of the piscine * circulation is that its central portion, i.e. in especial the heart and the vessels emerging from it, are still quite symmetric (see the drawing).

If we now compare the conditions just related with those obtaining in **Man**, the great difference which exists is obvious. Not only is the heart of Man (as that of the Mammals in general and also that of the birds) completely divided into two halves, each composed of an auricle and a ventricle, also the blood on its way through the body makes two separate circuits, while the symmetry observable in the fishes has entirely disappeared. I think I need not dwell on particulars since these will be sufficiently familiar to you from Anatomy; let me only state that from the general biological point of view these alterations mean a new division of the labour entrusted to the entire circulatory system; the most significant result of the process being that the purified blood, since it returns from the lungs to the heart, can by this be sent to the organs with new and full force, a thing which is impossible under the conditions prevailing in the Fishes. This specialisation between the "pulmonary" and the "systemic" circuits, in association with the extraordinary increase in size of the respiring surface of the lungs (p. 450) affords the anatomo-physiological explanation of the fact previously discussed that the Mammals and Birds are "warm-blooded" animals (see p. 9).

The remaining Vertebrates, that is, the **Amphibia** and **Reptilia** (p. 235) possess circulatory systems which represent most instructive intermediate stages between the piscine and the mammalian types, and the Amphibia in particular, during their individual development, still show the way in which the transformation from the one to the other has probably taken place. The heart of the adult frog (see Fig. 5, Pl. XXIII; the organ is drawn there from its dorsal aspect, a large part of the left half being omitted) is, as it were, "half-divided"; the ventricle being still simple as in the Fishes, while the auricle is divided into two (*RA*, right auricle; *LA*, left auricle) as in the Birds and Mammals. The original "ascending aorta", now represented by the "aortic trunk", appears outwardly simple, like the ventricle from which it emerges. This arrangement entails the following remarkable mode of circulation. The impure blood returning from the body is received in the right auricle, enters the ventricle, and is thence driven to the lungs by the pulmonary arteries *PA*; from these, it returns to the left auricle (see the bent arrow connecting *PA* with the pulmonary veins *PV*), but must now again pass through the ventricle in order to be distributed to the peripheral organs by the aortic arches *Ao*.

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* "Piscine"—from the Latin "piscis"—fish (see p. 235).

In the ventricle therefore the purified blood crosses the path of the impure blood and becomes mixed with it. It is true that a partition-wall, developed within the aortic trunk but not visible from outside (I will spare you details on account of the complexity of the structure), provides that the blood coming from the right auricle chiefly gets into that part of the aortic trunk which communicates with the pulmonary arteries, while the blood coming from the left auricle chiefly leaves by another part of the trunk which communicates with the systemic arteries; nevertheless, the fact of the mixture remains. In the drawing, Figure 5, Plate XXIII, the two circulations, in order to render them more easily distinguishable, have been shaded somewhat differently, namely, the pulmonary arteries in a darker, the systemic arteries in a brighter hue.

From the evolutional point of view there is thus a distinct, though as yet not very successful attempt at specialisation perceptible in the heart of the frog; I may here mention in passing, but without giving details, that the attempt is repeated with more success in the Reptiles ; for in these even the ventricle becomes divided into two ; this division being still imperfect in the lizards, snakes, and turtles, but becoming perfect in the crocodiles (see p. 236).

The main arrangement of the whole central portion of the circulatory system is still symmetric in the frog, although the asymmetry of the higher Vertebrates is distinctly foreshadowed by the partial division of both the heart and the adjoining portion of the aortic trunk. In this respect, also, the Reptiles advance further, the arrangement of their vessels being asymmetric with unmistakable remainders of the original symmetry. Thus, on the whole, the structure of heart and adjoining vessels in the adults of the different representatives of the Vertebrates presents an almost uninterrupted series of transitory phases between the primitive conditions of the Fishes and the specialised conditions of the Birds and Mammals.

If we conclude from these facts that the circulatory apparatus of the higher Vertebrates has become evolved from that of the lower in the way indicated by the transitory phases this conclusion is fully borne out by embryological facts. You will learn in human embryology that even in **Man** the vessels are not asymmetric from the beginning, but only become so during development; their first arrangement in the embryo being about as symmetric as remains the arrangement of the vessels throughout life in the Fishes. We have seen that, in the latter, this symmetry is the natural consequence of the presence and the special localisation of the gills. In Man, however, gills never exist, not even in the earliest periods of embryonic life, and yet the vessels formed at the same period are symmetric, thus comprising a number of sections which are of use neither to the embryo nor to the adult, and are in fact again abolished soon after their formation. This particularly roundabout developmental history would seem little logical at first sight, but appears in another light if considered from the evolutional point of view. Indeed, it is one of those facts to which allusion was made on page 403, and upon which our scientific theories about the gradual evolution of the organic world are based.

What in Man and the warm-blooded Vertebrates must in part be left to interpretation because it is only indicated by the earliest embryonic stages can in the frog be demonstrated as it comes to pass in the subsequent "post-embryonic" life. We know from a previous chapter (pp. 216ff) that the **frog** develops by metamorphosis: the larvae (tadpoles, أبو ذنيبه) living in water and respiring by gills, while the adults live on land and respire by lungs. In accordance with the life in water the **circulatory apparatus of the tadpoles** (Fig. 4, Pl. XXIII) is still the same in essence as that of the Fishes, the blood going from the simple heart to the gills in symmetrically arranged aortic arches, and thence collecting again in a median dorsal descending aorta (this course in the drawing again indicated by arrows). A particular feature about the aortic arches is that there are on each side four, while only three pairs of gills exist; so that one of the arches (the hindmost, see drawing) must go to the descending aorta without participating in the respiration of the tadpole. A behaviour to some extent recalling this state is found even in the three anterior arches; for, although these enter the gills and there break up into capillaries ([*Gi*]), a small side-branch (marked +) leaves each arch just before its entrance into the gill and joins the arch again immediately after its emergence from it.

In this form the tadpole lives and respires so long as it stays in the water, notwithstanding that the **lungs** of the adult frog develop in the meantime as outgrowths of the oesophagus. As they grow, the two hindmost aortic arches (i.e. the fourth arch of each side), which thus far had no particular function, join the lungs of their respective sides and become the pulmonary arteries, while two entirely new vessels, one on each side, establish a direct communication between lungs and heart and eventually become the pulmonary veins. The auricle is at the same time divided into two and the partition-wall in the aortic trunk arises. In a word, the tadpole, at this stage, still respires by gills, but has a circulatory system which is literally a combination of the piscine with the amphibian type and enables its owner to at any time dispense with the gills and all those sections of the vascular apparatus which connect them with the heart. This ability is made use of when the tadpole leaves the water to undergo its metamorphosis into the frog-shape. The gills become obliterated and the blood which previously passed through them now takes its way through the small side-branches above described, which connect the ventral and dorsal halves of the aortic arches at the base of each gill (+++, Fig. 4), and goes to the peripheral organs. Thus the three anterior aortic arches by which the respiration was hitherto effected are excluded from it, their place being taken by the hindmost arch which previously did not participate in respiration, but now leads the blood from the heart to the lungs. In connection with these essential changes certain tracts of the original system, which seem no longer necessary, also disappear, and so the circulatory system characteristic of the adult frog has arisen from that of the tadpole. In order to render the preceding description as comprehensible as possible the two diagrams, Figures 4 and 5, Plate XXIII, have been arranged in such a way that corresponding portions of the larval and adult circulation lie just opposite each other in the middle-line. In addition, the vessels of the tadpole, which have become obliterated during the subsequent metamorphosis, are still faintly indicated in Figure 5.

I have dwelt on the anatomy and development of the Vertebrate circulatory system a little more fully, because it affords instructive illustrations of those relations between ontogeny and phylogeny of the organisms discussed on page 402f.

(*b*) On the Relations between the Coelom and the Excretory Organs.

In the introduction to this chapter it was suggested that the coeloma, as it serves to distribute the food to the peripheral organs, so is also likely to receive the waste-products formed during the activity of these organs. We have indeed plenty of evidence to that effect; the most perspicuous item being that the coeloma, wherever it is developed, directly or indirectly communicates with the exterior by apertures the presence of which would be meaningless if there were nothing to be eliminated by them. With reference to particulars, the excretory system presents among the Coelomates a similar gradual progress from simple to ever more complicated conditions as we found in the circulatory and respiratory systems. Moreover, whilst these two enter into ever closer connection with the gradual progress of their specialisation, the excretory system becomes involved commensurately, the result being that in the end all three systems form, anatomically and physiologically, a whole almost inseparable. A few steps in this evolutional process may here shortly be described.

We know that, for general reasons (p. 12f), the waste-products of metabolism cannot remain in the body; so it seems reasonable to assume that, as soon as the coelom is developed and receives the waste-products, certain cells of its lining will devote themselves to the work of eliminating them. They may, initially, perhaps simply absorb them and store them in their bodies; however, as the efficiency of this device is limited, the necessity will sooner or later arise for the cells to communicate with the outer world, i.e. to pierce the body-wall and void the products. If the body-wall is somewhat thick, a canal within the cells will be useful for the process. We here have in principle the structure of the excretory system of many lower Coelomates, among others the **Nematodes**. If we duly examine these a longitudinal row of cells (sometimes short, sometimes long) is found on either side, adhering to the body-wall and projecting more or less markedly into the body-cavity. Each row is pierced by a continuous canal closed at its inner end and opening to the exterior at the other (both canals, by the way, through the same pore, called the "excretory pore"). An exceedingly suggestive addition to this structure of the excretory apparatus is found e.g. in the **Trematodes** and consists in the slightly funnel-shaped blind ends of the excretory canals becoming equipped with cilia-like structures (Figs. 1, Pl. XI, 6, Pl. XXIII) which by their movements produce an outward bound current in the liquid contents of the canals (compare here the discussion on p. 85).

In the cases hitherto mentioned the excretory substances can only reach the exterior by a passage, or a kind of filtration, through the cytoplasm of the excretory cells, into their axial canals. In other cases, however, the canals break through into the coelom, usually by an opening the margin of which bears a crown of cilia, a direct communication between the coelom and the outer world being thus established. An example of this type is supplied, among others, by the **earthworm** the excretory organs of which (see Fig. 7, Pl. XXIII) are fairly long cellular strands laid up into several S-shaped loops and enclosing a fine tortuous canal (*Can*), which on one side communicates with the coelom by a vibrating funnel (*NSt*), while the other end pierces the wall of the ventrolateral aspect of the body (*Op*).

Similar conditions must have prevailed in the primitive **Vertebrates**, for they actually occur even at present in both the adult stages of their lower grade representatives and the embryos of the higher. In the Vertebrates, however, the far-reaching separation between coelom and circulatory system leads to complications which begin with the blood-vessels seeking the excretory canals and end with the replacing of the original, but apparently no longer satisfactory, excretory system by an entirely new apparatus of different structure and origin. Some special examples will make this process clearer.

The first form in which the "kidney" arises in the embryos of nearly all Vertebrates is that of the "**Pronephros**"*. This is a simple canal lying on either side in the somatic wall of the coelom and opening, posteriorly, (usually) into the terminal portion of the intestine, while in the neighbourhood of the head it communicates with the coelom by a ciliated funnel. A few similar funnels, technically called "**Nephrostomes**", or "**Nephridia**"*, lie at short intervals behind the first, and by delicate "nephridial canals" seek connection with the longitudinal "pronephric" canal. The conditions are diagrammatically shown, in surface-view, in the upper portion of Figure 8, Plate XXIII (*NSt* representing the few nephrostomes; *PNC* the slightly tortuous pronephric canal) and, in cross-section, in Figure 9, Plate XXII. In this latter figure, we see, in the median plane of the embryo and below one another, the cross-sections of the nervous system (*Nrv*), the notochord (*Nch*), the descending aorta (*BlV*), and the mesentery (*My*; see p. 437), while to the left, in the substance of the body-wall, there lies the cross-section of the pronephric canal *PNC*, communicating with the coelom by the nephrostome *NSt*. There is no direct association with the circulatory system; the pronephros can in fact only eliminate such waste-products as have been emptied into the coelom, and does so by the nephrostomes.

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* From the Greek νεφρός—kidney; pronephros meaning about "the first kidney".

However, an indirect communication between the two systems under consideration exists even in this primitive condition; for, just opposite each nephrostome, a slight bulging is seen to project into the coelom, which, within its mass, contains a coil of fine blood-vessels (*Gl*, Fig. 9) sent out by the descending aorta (*BlV*). There is little doubt that these small coils of vessels, known under the name "**Glomeruli**", close to the surface of the coelom as they are situated, are destined to allow the waste-products carried by the blood to escape into the coelom, whence they can be taken up and eliminated by the nephrostomes. In this primitive state we find the excretory organ throughout life in certain lowly organised Fishes ; in all other Vertebrates it is present, also, but only in an early period of the individual development, while in the later stages it is transformed into another system, the

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* From νεφρός and στόμα—see note *, p. 84.

"**Mesonephros**"*. This is in essence nothing but an enlarged and improved pronephros (see posterior portion of Fig. 8, Pl. XXIII), consisting of very numerous nephridial tubules which develop after and behind the primary ones (*NSt*, Fig. quoted). Like these, they communicate by nephrostomes with the coelom and on the opposite side open into the posterior part of the pronephric canal which is thereby converted into the "mesonephric" canal (*MNC*, Figure quoted). While the pronephros was still entirely buried in the wall of the somatic portion of coelom the complex of the mesonephros becomes usually somewhat raised above the level of the surrounding, thus projecting into the coelom as an individualised body ; its distinctive character, however, is that blood-vessels enter it in large numbers and seek each a connection with one of the nephridial tubules. This connection is most interesting and consists in the wall of each tubule near the nephrostome growing out into a hollow pouch-like appendage into which from the opposite side a small blood-vessel enters, forming some coils within the pouch and then leaving again at its place of entrance. We call these minute structures, from the name of their discoverer, the famous Italian naturalist Marcello Malpighi, "**Malpighian corpuscles**", while the vascular coils are the "glomeruli" already mentioned. The changes described are illustrated by Figure 10, Plate XXII. We here see, in cross-section, particulars similar to Figure 9, except that the longitudinal canal cut across is the mesonephric canal (*MNC*), and that the vascular coil *Gl* is enclosed in a pouch sent out by the (somewhat longer and more tortuous) nephridial canal. The function of the whole mechanism is fairly clear; for the blood, while it passes through a glomerulus, is able to give up any waste-products it may contain through the vascular walls into the pouch of the Malpighian corpuscle, from which they can be voided into the mesonephric duct and thence to the exterior.

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* From μέσος—see note *, p. 436, and νεφρός ; therefore : the "middle-kidney".

In the form here described the kidney exists and functions throughout life, among others, in the frog and other Amphibia; it deserves our interest chiefly on account of its abstracting excretory products from both the coelom (by the nephridia) and the blood (by the Malpighian corpuscles).

We have seen above that the nephridia are not absolutely necessary; the excretory cells, as shown by the Nematodes and Trematodes, being able to absorb waste-products through their cytoplasm and thus remove them with equal ease by open and by blindly closed nephridial canals. Under these circumstances it is not strange that (e.g. in many Fishes) the mesonephros, although in all other respects the same as that of the frog, has no longer any nephridia but only blindly closed nephridial tubules. The respective conditions are shown under a somewhat higher enlargement in Figure 9, Plate XXIII; there is the mesonephric canal *MNC* and the pouch, with the glomerulus *Gl* formed by the blood-vessel *BlV*; but in place of the nephridial canal and the nephrostome we only see the short and blindly closed stump [*NSt*]. It seems possible, as I just said, that this excretory system is still capable of extracting waste-products from the coelom; there is no doubt, however, that the bulk of the excreted matter must here be supplied by the blood.

If we now look at the various shapes exhibited by the excretory systems of the lower Vertebrates (i.e. the Fishes and the Amphibia) from a comparative point of view, they clearly suggest an increasing participation of the circulatory system in the process of excretion, while the coelom, which originally did the work alone, is gradually being released from it.

The change just alluded to is completed in the warm-blooded Vertebrates. We have seen above that their vascular apparatus, highly specialised as it is, has almost entirely taken upon itself the distributive function which originally was performed by the coelom; it now does the same with regard to the excretory duties of the latter. For this purpose, Mammals, Birds, and Reptiles, which in their embryonic development at first form a pronephros followed by a mesonephros like that above described, eventually produce a third form of kidney, the "**Metanephros**"*, while the mesonephros simultaneously disintegrates. The definitive kidney of these animals therefore orginates in the same roundabout way—and the process has the same significance—as we previously saw in the case of their blood-vessels (p. 456). As to particulars, I think I can dispense with them here as they come within the range of your Anatomy- and Embryology-lectures.

In conclusion a few remarks may be made about the **genital organs**. We stated on page 442 that the sexual cells are supplied from the mesoblast and (usually) originate in particular areas of the coelomic epithelium. Under these conditions any sexual cells, if after maturation they become detached from their bed, must first get into the body-cavity and thence be evacuated. Considering the existence and the special structure and function of the nephridia it seems natural that these should play a part in the process. In a large number of Coelomates indeed the **outlets of the genital organs are modified nephridia.** This is also the case in the Vertebrates, in which both organs enter into so intimate a structural and functional association with one another—an association traceable from beginning to end in the embryonic development—that in the adults they form the complex of the "**Urogenital System**".

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* From νεφρός and μετά—see note *, p. 231, the "after-kidney".

D.—The Metameric Architecture of the Body.

We saw on page 411 that the primitive shape of the metazoan body was in all likelihood that of a spherical bladder. Since in a bladder there is no distinction between anterior and posterior, or right and left, or dorsal and ventral aspects, the organisms which possessed this shape can only have lived in a medium which surrounded them equally on all sides; that is, they must have lived freely floating in water; and it is probably no mere accident that the free-swimming blastulae of certain lower animals (see p. 410) as well as the colonies of *Volvox* (p. 255) actually have this mode of life.

Some of the early spherical metazoa may subsequently have exchanged the vagrant for a sedentary life by fixing themselves to some other object. This would naturally entail a distinction between the fixed and the opposite free end of the body, which latter, in its turn, was likely to collect round itself any structures by which the organisms communicated with their surrounding, such as e.g. mouth-opening, subsidiary organs for feeding, sense-organs, and others. It is probable that in this way the radial architecture arose, of which *Hydra* is an example (p. 419). At any rate, reflection shows that the radial architecture, also, is only possible in aquatic organisms.

In order to understand this, let us suppose that a *Hydra* goes on land. While in the water, small organisms suitable for food were always likely to come its way, thus dispensing it from the necessity of moving about in search of food, the same probability is so much reduced on land that more frequent movements from one spot to another will become unavoidable. These movements, in their turn, will entail, as the most important among other consequences, a change in the former attitude of the body. The long axis, previously standing off at some angle from the support, will now have to lie upon this, and, instead of an end, a side of the body faces the surface of the ground, while the opposite side is turned away from it. In other words, the frequent movements will differentiate a dorsal from a ventral aspect and, in association therewith, a differentiation between a right and a left side. We can thus understand that a life on land is bound to bring about, sooner or later, what we formerly called a "bilateral symmetry" of the body (p. 231), although on the other hand a life in water does not of course prevent aquatic animals from assuming the same architecture when similar conditions of feeding and movement demand it.

The successive changes here described in the architecture of the metazoan body, if taken as a whole, would suggest that the earliest Metazoa which populated the earth were aquatic, while land-animals did not arise until later on. This inference is in full harmony with the facts brought to light by Geology; for these leave no [illegible] doubt that in former times a much larger area of the surface of the earth was covered by water, and that, originally, probably no firm land at all existed.

The assumption of the bilateral symmetry in the external shape must naturally be associated with a change in the arrangement of the internal organs. Without going into details I will here only state that in accordance with the laws of equilibrium all the organs present as units are so far as possible collected in the axis, or, at any rate, in the plane of symmetry of the body (p. 231), whereas those present as pairs, or multiples of two, are placed on either side of this.

We have repeatedly spoken of the tendency to progress and perfection innate in the living organsims. Let us now enquire (quite theoretically) what would be the probable result if the above tendency came to act in an elementary, bilaterally symmetric animal. The possibility which most naturally offers itself is that the latter simply grows; since, however, in this case the bulk of the body, according to mathematical laws, will increase far more considerably than does the surface (the relative size of which we know is of fundamental importance in all processes of absorption; see, e.g. p. 30) this possibility of advance seems limited from the beginning. On pages 407ff we saw that another probable method of progress is partial division with subsequent colony-formation. Supposing that it were adopted the result would, first of all, differ somewhat according to the direction of the division. For if it takes place longitudinally the (incompletely separated) daughter-individuals must come to lie, either one above the other, or one besides the other, two situations neither of which appears very propitious to locomotion (the process seems possible in the case of radiate animals in which it would lead to a multiplication of the antimeres). There thus remains for the bilaterally symmetric animals the transverse division which would yield daughter-individuals situated one behind the other. We know from previous cases (e.g. *Paramaecium*) that under these conditions the proper act of division is usually preceded by a stage in which the original individual with all its organs appears doubled (see p. 127); presumably, therefore, a similar stage will represent the end of the incomplete division of our bilaterally symmetric organism. We have thus two individuals, permanently attached to each other, and simplified, perhaps, in that their unpaired organs (as e.g. the intestine) may pass through both without apparent interruption. The pair arisen in this way will subsequently divide again after the same fashion, and so will its descendants, the colony thus assuming by degrees the shape of a chain of individuals. These latter, though united into a whole, yet all have the same organisation which in case of emergency would enable them to live separately as did the mother-individual from which they derived their origin. A slight exception would only be made by the foremost and hindmost links of the chain which, as they alone can contain, the former the commencement, the latter the end of the unpaired organs (such as e.g. the intestine) would show particularities in association with these structures.

Apart from this, all individuals are essentially alike and consequently would equally participate in the vital functions of the colony. However, the division of labour we found in the *Volvox*-colonies tends to show that the function of reproduction may without harm to the whole be taken away from the majority of the individuals and handed over as a special task to some which then reproduce the race for all the others, while these, in exchange, provide them with food. If a similar process were to take place in the chain-like colony of our assumed organism its result would be that the majority of the individuals lose their genital organs, while only some retain them, and perhaps even enlarge them.

The evolutional changes which I have here outlined are merely hypothetical; but the interesting thing is that they would yield a structure of the metazoan body which is actually realised in the earthworm. A brief description of its external and internal organisation will make this apparent.

E. — The Earthworm.

(Plate XXIV).

The earthworms, members of the scientific genera *Lumbricus* and others, live in earth or mud permeated with organic (chiefly vegetable) debris. Their general shape will be familiar to you; it is long, "wormlike"; the two ends are somewhat pointed, the dorsal and ventral aspects slightly flattened and somewhat different in colour. The most characteristic feature is the presence of a large number of transverse constrictions by which the body is divided into short "segments" or "metameres" (p. 231). From without, they look all much alike with the exception of the first one or two, which contain the mouth-opening, and the last one, which bears the anus. There are no external appendages; the **locomotory organ** of the earthworm being its "dermo-muscular coat". This, as indicated by the name, is represented by the skin and an underlying double layer of muscle-fibres. As these latter run longitudinally in the inner layer and run transversely in the outer, both sets act as antagonists to each other just as the muscles of the human intestine (p. 37) and the epithelial muscles of *Hydra* (p. 415). In order to utilise their alternate contractions and extensions for locomotion the eartworm possesses, in the sides of each segment, bundles of fine, stout bristles (*Se*, Fig. 2) which slightly project over the body-surface in a backward direction.

If an earthworm, lying with these bristles freely on an absolutely smooth surface (e.g. a glass-plate), extends itself by a contraction of its circular muscles the main result will be that the anterior end glides forwards, the posterior end backwards, while the middle of the body remains about the place. If on the other hand an earthworm finds itself on a slightly rough surface the bristles pointing backwards must, when it commences to stretch, rub against all the slight roughnesses of the surface, and will thus prevent the gliding backwards of the posterior half; i.e. they will only permit the anterior end of the worm to glide forwards. The same must take place when the body again shortens; for now the bristles of the anterior half, as they point backwards, will prevent this half from withdrawing, the result being that only the posterior end can be dragged forwards and towards the anterior. So the backward direction of the bristles only allows a forward movement of the worm. In all countries where earthworms are common it is a familiar fact to gardeners and boys that an earthworm protruding with a part of its body from a clot of broken up earth may easily be pulled out of its hole if the protruding end is the anterior end, whereas it will invariably be torn if the protruding part is the posterior end; the reasons are easily inferrable from what has been said above.

On opening an earthworm we first notice that the annular constrictions of the body-surface are continued inside into fine membranes, the "**Dissepimenta**"

(*Di*, Fig. 1), which, extending through the coelom, shut each segment completely off from the preceding and following segments. They are only perforated in their middle by the rather voluminous intestine (*In*, Fig. 1) which runs through the whole length of the body in a straight line, showing various sections—products of a division of labour like the sections of the human intestine—which I abstain from enumerating separately. The **food** of the earthworm consists in organic debris which it takes up along with the earth containing them (in this way, it also swallows *Gregarina*- spores, if these are present in its neighbourhood; see p. 138). The view frequently met with among the country-people that the earthworm feeds on the roots of living plants, is erroneous; the animal is, on the contrary, an extremely useful creature inasmuch as by burrowing about in the earth it breaks this up and thus facilitates the entrance of air which we know is necessary for the plants growing in the earth.

All along the dorsal surface of the intestine, and closely applied to it, we perceive a dark red streak: a **blood-vessel** (*DV*, Figs. 1 and 2). It grows slightly thicker as it runs forward, and in the neighbourhood of the head breaks up, on either side and at regular intervals, into five fairly wide lateral arches (*H*, Fig. 1) which encircle the gut in a ventral direction and beneath it again collect into a thick vessel which runs backwards in the midventral line (*VV*, Figs. 1 and 2; in the former just visible under the cut end of the intestine). Fine lateral branches leave this vessel in each segment, seeking the peripheral organs and then returning to the dorsal vessel. Since the hindmost of these lateral branches represent the commencement of the dorsal vessel the circulatory system of the earthworm is closed, as mentioned on page 447. Its fairly regular arrangement is largely due to the absence of particular respiratory organs; the respiration going on as described on page 448. The blood is a red fluid containing some amoeboid, but colourless "blood-corpuscles", and flows in the direction above given; the "heart" being represented by the wide vascular arches *H* above described which have contractile walls.

Below the gut and in the median line of the ventral body-wall we find the **nervous system** which thus has the ventral position characteristic of all Invertebrates (see p. 235). When seen with the naked eye or a pocket magnifying glass, it appears like a row of tiny beads; a slight swelling (scientifically termed a "ganglion"; see also p. 232) occupying the middle of each segment, while somewhat narrower strands connect it with the ganglia of the preceding and the following segments (*G*, Fig. 3). Only in the head it deviates from this behaviour, in so far as the foremost ventral ganglion transmits, anteriorly, two connecting strands which embrace the intestine on either side and on its dorsal surface again coalesce to form a (double) dorsal ganglion. This noose, or **nerve-collar**, poorly developed as it is, represents the "cerebral" nervous system of the earthworm, its constituent parts being scientifically termed the "supra-oesophageal" and "infra-oesophageal" ganglia (*SoG*, Figs. 1 and 3; *IoG*, Fig. 3) with the "cerebral commissure" uniting them.

The essential structure of the **excretory organs** has already been described; so it only remains to say that (with some exceptions to be explained presently) they are found one pair in each segment (*Nph* Fig. 1), being connected with the dissepimenta in such a way that they adhere to their posterior aspects (*Di*, Fig. 7, Pl. XXIII) while the funnels perforate them and open into the coelom on the further side (*NSt*, same Figure). It comes about by this singular behaviour that the nephridia of a segment always evacuate the waste-products of the preceding segment.

While the organs thus far described clearly exhibit the "metameric" arrangement, showing in this way that each segment contributes an about equal share to both the structure and the vital functions of the whole, the **sexual organs** take exception to this conduct. They are only present in some of the anterior segments (the 10.-14.) and are represented by both testicles and ovaries, their outlets being modified nephridia (p. 465). As the details of their structure are of special zoological rather than of general biological interest, I do not deem it necessary to describe them more fully; they are shown in Figure 1, Plate XXIV, the male organs being marked ♂, the female ♀. For the mode of copulation see page 154.

Among the biological peculiarities of the earthworm a prominent position is held by its regenerative power which is almost as remarkable as that of *Hydra*. Numerous experiments have shown that a specimen can be cut up into portions averaging not more than a centimetre in length and that, under otherwise favourable conditions, these will all again grow out into new individuals. Under these circumstances it may be anticipated that transplantation will succeed with equal ease; in fact the earthworm is a favourite object for research in transplantation, of tissues as well as of whole parts of the body, with experimental biologists.

Some of its relatives furnish those examples of natural regeneration in connection with reproduction by division, to which allusion was made on page 185. In a small species of earthworm inhabiting fresh waters of Europe one may at times observe that a specimen spontaneously and rather suddenly breaks asunder into a number of pieces which, with the exception of the foremost and hindmost ones, have neither a head nor a tail, but regenerate these in due time and thus grow out into new complete worms. The same phenomenon also occurs in other forms, and, since it raises the impression of the animals cutting themselves up into pieces, as it were, of their own accord, has received the name "**Autotomy**"*; it is a peculiar variety of asexual reproduction by division. In other relatives of the earthworm, chiefly of marine habits, the division does not take place suddenly, but prepares itself, so to speak; the body becoming either simultaneously marked off into several parts by constrictions, or similar parts growing gradually out, one after another, from the posterior end (*B* in Fig. 4, Pl. XXIV). In either case, the partitions, before detaching themselves from the mother-individual, form new heads and, where required, new tails, the whole then assuming for a time the extraordinary appearance of a chain of complete worms placed end to end (Fig. 4). Very interesting sexual conditions are frequently combined with this multiplication, but cannot be followed up further.

* Greek from αὐτός—see note *, p. 150 and τομή (from τέμνω) —a cut.

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